STREAMFLOW SYNTHESIS EMPLOYING A MULTI-ZONE HYDROLOGIC MODEL WITH DISTRIBUTED RAINFALL AND DISTRIBUTED PARAMETERS

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CHAPTER I

INTRODUCTION

The development of methods to better estimate the hydrologic response of a watershed and the application of these methods in practice is the science and art of hydrology. That aspect of hydrology known as streamflow forecasting undertakes to predict the outflow from a given catchment, in terms of flow rate as a function of time, in response to a given precipitation event under given initial conditions. This capability is vital to effective planning for urban/industrial development, flood control hydroelectric power, navigation, water pollution control, and general water resources management.

The hydrologic cycle is rather easy to describe in qualitative terms. The principal components of the cycle have been identified and the interactions between the major components are well known. However, the extension of this qualitative knowledge about the hydrologic cycle to obtain quantitative results is a difficult task. Perhaps few basic quantitative concepts exist in hydrology, compared to other fields. It may never be possible to develop hydrology into a mathematically precise science; however, predicting watershed response from basic hydrologic data became a sophisticated science with the advent of digital models of the hydrologic cycle. Research into such simulation models began at Stanford University in 1959 (1)(2)(3), and with the growing availability of large, high-speed computers, hydrologic modeling became popular. Most latter-day models perform a quantitative analysis of hydrologic regimes by establishing continuous mathematical relationships between elements of the hydrologic cycle, using digital computers to carry the calculations forward in time. The mathematical relationships developed attempt to reproduce realistically physical processes in the model. Experimental results and analytic studies are used where possible to assist in defining the necessary relationships.

Precipitation and potential evapotranspiration are the basic inputs to most conceptual models, and actual evapotranspiration, streamflow, and soil moisture levels are generally obtained as output. The term "conceptual" indicates that the model reproduces the concept of a process rather than being a physical replica. The model must simulate basin response on a continuous basis, rather than treat only isolated events. In other words, calculations are made on selected time intervals continuously, whether or not precipitation is occurring, to simulate the entire spectrum of watershed behavior. Data requirements for the development and application of these complex hydrologic models are vast. Several years of streamflow must be simulated using actual precipitation data and computed evapotranspiration demand. Synthesized flows are then compared to actual recorded flows, and model parameters adjusted by hydrologists until acceptable simulation accuracy has been achieved. Only when so verified can the hydrologist claim that the model is a sound tool for predicting stream behavior.

While the digital simulation model is a recent development, numerous researchers during the past decade have succeeded in integrating hydrologic empirical/mathematical relationships into comprehensive parametric models that synthesize flows accurately for most hydrologic events. And if the model is conceptually correct, it should be applicable to any basin under all hydrologic circumstances. Unfortunately, this is often not the case. For a number of possible reasons the model may fail to perform properly in response to a given precipitation event, even though verification against historical flows indicates the model is properly calibrated for the watershed. Part of the simulation problem could be that the temporal runoff process, which is physically nonlinear, is modeled by a linear mathematical function--a unit hydrograph. Some of the error may be due to averaging precipitation over the entire basin, when in fact the common intense convective rains are likely to cover only a fraction of the watershed during a storm event. Since a uniform distribution of rainfall over a basin may be more the exception than the rule, any hydrologic model that requires such an averaged (lumped) rainfall input has inherent deficiencies. Of course, the rain gage network is seldom optimum, so that an exact delineation of the true rainfall pattern is probably impossible. However, more often than not, sufficient point rainfall values are available such that the analyst can at least determine "heavy upstream or downstream" rainfall distributions, thus allowing for sub-area (distributed) rainfall input to the model. If one then structures the model to couple the sub-area rainfall input to an inflow channel response function (time-delay histogram with variable K storage routing capability), rather than apply a basin averaged rain to an outflow unitgraph, there is opened up the possibility of simulating flows under storm conditions that cannot be handled consistently with existing modeling procedures. A distributed input model also provides separate soil moisture accounting with each sub-area (zone), effectively maintaining individual zone moisture storages that could allow for better low flow reconstitution while improving high flow simulation during non-uniform rains.

Besides treating watersheds with basin averaged rainfall, typical hydrologic models view the catchment as lumped parameter systems. By "lumped" it is meant that each parameter value obtained during calibration represents an average value for that parameter over the entire watershed in question. It is well known, of course, that certain physically realistic parameters in a model, like infiltration capacity or lower zone aquifer storage capacity, may take on widely differing values across a watershed. One cannot help but be intrigued at the possibility of establishing unique parameter sets for each rainfall zone (distributed parameters), thus recognizing, for example, the low infiltration-low moisture storage and high runoff characteristics of the basin headwaters versus the downstream hydrologic characteristics of an alluvial plain. However, whether or not it is possible to intelligently ascertain such unique parameter sets and improve simulation significantly is an open question.

The improvement in streamflow synthesis possible through the design and use of a multi-zone (distributed) hydrologic model to account for the spatial variability of rainfall and parameters is a fertile area for research. A study of this nature requires the following:

1. Assemblage of a hydrologic data base of sufficient size and accuracy for several watersheds so as to allow detailed hydrologic model research.

2. Construction of a conceptual hydrologic model simulation system (computer program) utilizing a proven soil moisture accounting procedure and capable of handling catchment distributed (zonal) precipitation input

only, or both distributed input and distributed parameters.

3. Calibration of both the lumped catchment model and multi-zone models for each watershed.

4. Evaluation through statistical analysis and analytical procedures the performance characteristics of all three model types.

This report presents the methods and results of such an investigation on eight watersheds in the southeastern United States with a total record period of 55 years. Chapter III describes the watersheds selected for model research. Chapter IV elaborates on the generation of a hydrologic data base, and Chapter V explains the conceptual model formulated and applied. Chapter VI details research procedure and discusses the performance characteristics of the hydrologic model operating in three simulation modes.

CHAPTER II

LITERATURE REVIEW

Though the science of quantitative hydrologic modeling is young, the research effort expended to promote and improve simulation models is considerable. Each new model seems to generate a family of "spin-off models," each of which represents a particular author's effort to better reconstitute the hydrologic behavior of watersheds in a given geographical area. Since a hydrologic model is nothing more than a collection of quantitative hydrologic concepts that are given mathematical representations, there is the potential for an infinite variety of these simulation systems. However, published literature on distributed models is almost nonexistent.

Early simulation studies were reported by D. R. Rockwood (4) in developing digital methods to monitor flow in the lower Columbia River, and by Professor Hardy (5) of the University of California in developing techniques for the simulation of flood flows in rivers (5). The first comprehensive discussion of the present version of the Stanford Watershed Model was published by Crawford and Linsley (6) in 1966. The Stanford Watershed Model is complex, but truly conceptual in nature, and is probably the most widely studied and applied parametric model in the world. It might justly be termed the father of modern-day digital simulation models. Since originally published in 1962, several reports have appeared in the literature describing modified versions and applications (13)(14)(15)(16)(17)(18). The talents of the Corps of Engineers and National Weather Service were combined to create the Streamflow Synthesis and Reservoir Regulation (SSARR) Model reported by D. M. Rockwood (7) and V. P. Schermerhorn (8). First developed in 1957, the model proved capable of simulating flows due to both rainfall and snowmelt runoff under a variety of anticedent conditions over the Columbia River Basin. While perhaps not truly a conceptual model, the SSARR soil moisture accounting procedure is simple and effective.

Small watershed models have proven effective and are popular with many water resource agencies of the Federal Government. The Department of Agriculture Hydrological Laboratory (USDAHL) Model (9) was developed from a 2.37 square mile experimental watershed in Ohio, and is capable of continuous streamflow simulation. While proven for smaller catchment application, Linsley (10) is of the opinion that the model is not particularly adaptable to large watersheds. The U. S. Geological Survey and Soil Conservation Service employ similar catchment models, with apparent emphasis being placed on high runoff flow simulation.

Sittner, Schauss, and Monro (11) report on a four-component hydrologic model that has been tested extensively on large watersheds. It is a complete simulation system utilizing an antecedent precipitation index type rainfall-runoff relation to compute surface runoff. Two important features of the model are the ease of adjusting parameters to observed flow and the sequential development of the four basic parts with a minimum of interaction. Burnash, Ferral, and McGuire (12) have developed a streamflow simulation model to reconstitute flow by including all the significant components of the hydrologic cycle in a simplified manner, which is consistent with observed soil moisture profiles.

Each parameter/variable has a physical counterpart, and certain key parameters can be derived from historical hydrographs. Thus, the calibration procedure becomes easier and one may have more confidence in the physical significance of the developed quantities.

Multi-zone hydrologic modeling attempts appear to be rare. Perhaps this is due to the general satisfaction with the simulation results from total area catchment analysis. And where models have been used in such a fashion, the emphasis has been on improving snow melt input to the simulation package. In the multi-zone mode, the SSARR Model (8) has demonstrated ability to simulate snow accumulation and depletion in an area which has a semi-permanent seasonal snow pack as well as ephemeral snow. Sugawara and others (19) have developed an interesting hydrologic model that conceives of water being held in storage in a series of tanks arranged one above the other, with individual tanks representing various storage zones in the soil mantle. This configuration is a suitable representation of the rainfall-runoff process in humid regions. For arid or semi-arid catchments, a variation--sometimes called the Composite Tank Model--is used. The Composite Model consists of two or more simple tank models arranged side-by-side in rows with the outflow from each row feeding into the adjacent row. The outflow from the last vertical row supplies the channel system. The several rows represent zones in the catchment, the lowest corresponding to the zone nearest the channel system. As hydrologic conditions make seasonal progression between wet and dry, the zones nearest the channel system may be more moist than those farther away. The Composite Tank Model, then, may perhaps be visualized as a distributed parameter model of sorts. Certainly it is an extremely flexible model since changes in the values of model parameters can actually change the structure of the model. Anderson (21) has applied multi-zone modeling concepts to a laboratory basin while Burnash (22) has attempted to distribute Sacramento Model parameters by working "downstream to upstream" over a basin in calibration mode to determine components of flow.

Morris (2) has investigated the use of the Stanford Model programmed to run in the distributed mode. As reported by this author at the First Conference on Hydrometeorology of the American Meteorological Society, the calibration of a distributed input-distributed parameter model is feasible, and indications are that significant improvement in simulation accuracy may be obtained under certain hydrologic conditions. However, the literature search failed to yield any information on other simular studies regarding multi-zone conceptual model design and application. The relative performance of multi-zone modeling versus catchment total area modeling remains unknown.

CHAPTER III

SELECTED WATERSHEDS FOR MODEL TESTING

Introduction

Whether for the purpose of hydrologic model development or "simple" basin calibration, an extensive historical data base, reasonably free of error, is mandatory. For researching a distributed model, the requirements are even more strict: the watershed must be geographically located so as to be exposed to numerous non-uniform precipitation events, exhibit hydrologic characteristics such that the lack of rainfall uniformity produces a different hydrologic response from that caused by a uniform precipitation event and, finally, an adequate precipitation gage network must exist so as to allow at least a crude determination of areal rainfall differences. Since for the purposes of this investigation snow is to be excluded, the modeled basins must also be mostly snow-free. After considering more than 25 watersheds in the southeastern United States--an ideal climatic regime for intense, isolated air mass type thunderstorms--eight basins were selected, seven headwater and one local area catchment, ranging in size from 233 square mile drainage area to 1162 square miles. Soil type and topographical maps combined with personal knowledge of the basin response habits served as the basis for final selection. Precipitation gage networks are typical for most catchments the hydrologist is likely to deal with, and appear to be adequate for distributed model research. Basins with more dense gage networks can be found, but in the author's opinion, the use of such catchments would preclude the extension of distributed model research results to other areas where gage networks are not ideal. Three watersheds are in Mississippi, two in Louisiana, and one each in the states of Arkansas, Missouri, and Tennessee. Tables I through VIII present summary gage data for each basin useful to the model researcher, and pertinent river gage histories that may have a bearing on simulation performance. The simulation period of record chosen for model study was based on not only the quality of streamflow records for any given period, but also the quality of precipitation data. For modeling purposes, a continuous record of high quality data at least five years in length is desired.

Elk River - Fayetteville, Tennessee

Fayetteville, Tennessee, is centrally located in Lincoln County about midway between the headwaters and the mouth of the river. The drainage area of the Elk River at Fayetteville is approximately 897 square miles. The river has its origin in Grundy County in the eastern part of the Highland Rim physiographic province, a gently rolling area cut into deep narrow valleys by the streams. The stream then flows southwestward through Tennessee and Alabama before entering the Tennessee River above Wheeler Dam. In Lincoln County, the river flows along the southern edge of the Central Basin province, an area characterized by numerous short valleys of comparatively smooth land separated by steeply sloping hills and sharp, narrow-crested ridges. These hills and ridges are spurs and remnants of the Highland Rim.

TABLE I

SUMMARY RIVER GAGE DATA - FAYETTEVILLE, TN

BASIN: ELK RIVER above FAYETTEVILLE, TN

GAGE NUMBER	03582000
GAGE TYPE	Water Stage Recorder - 1965 to present
GAGE ZERO	650.58 feet above MSL
DRAINAGE AREA	827 mi^2 897 mi^2 (planimetered area)used in study
PERIOD OF RECORD	8/34 to present
HISTORY OF GAGE LOCATION SINCE 1964	Lat 35°08'04", Long 86°32'23", Lincoln County, on right bank 100 feet downstream from highway bridge. 1 8 miles southeast of Fayetteville. 4.0 miles upstream from Norris Creek. At mile 93.9 from Mouth.
MAX FLOW	41,600 cfs (28.63 feet) on 3/16/73
MIN FLOW	67 cfs (.75 feet) on 12/9-11/1970
AVG FLOW	40 Years 1,430 cfs
BANKFULL FLOW	9700 cfs (19.6 feet USGS Gage)
QUALITY OF RECORDS	Excellent: 1966, 1969 Good: 1964, 1965, 1967-68, 1970
REMARKS	Flow regulated by Wood Reservoir since 1952, and Tims Ford Lake since December, 1970. Simulation period of record: 10/64 - 9/70.

TABLE II

SUMMARY RIVER GAGE DATA - IMBODEN, ARK

BASIN: SPRING RIVER at IMBODEN, ARK.

GAGE NUMBER	07069500
GAGE TYPE	Water-Stage Recorder - 1964 to present
GAGE ZERO	254.07 feet above MSL
DRAINAGE AREA	1162 mi^2 1965-1972 1183 mi^2 1973-1975
PERIOD OF RECORD	2/36 to present
HISTORY OF GAGE LOCATION SINCE 1964	Lat 36°12'19", Long 91°10'19", SE 1/4, NE 1/4, Sec. 15, T18N, R2W, Randolph County. Additional Changes: 1.8 miles upstream from Harding Creek; 8.2 miles upstream from Eleven Point River.
MAX FLOW	78,500 cfs (28.42 feet) on 1/24/49 Approximately 125,000 cfs (32.1 feet) during 8/1915 prior to records
MIN FLOW	215 cfs on 8/1/36
AVG FLOW	39 Years 1385 cfs
BANKFULL FLOW	Approximately 6800 cfs (12.0 feet)
QUALITY OF RECORDS	Good: 1965 through 1971
REMARKS	Low Flows regulated by Power Plant at Mammoth Springs 44 miles upstream, through 1970. Simulation period of record: 10/67 - 9/71

TABLE III

SUMMARY RIVER GAGE DATA - PATTERSON, MO

BASIN: ST. FRANCIS RIVER near PATTERSON, MO

GAGE NUMBER	07037500
GAGE TYPE	Water Stage Recorder - 1965 to present
GAGE ZERO	370.45 feet above MSL
DRAINAGE AREA	956 mi^2
PERIOD OF RECORD	10/20 to present
HISTORY OF GAGE LOCATION SINCE 1964	Lat 37°11'40", Long 90°30'10", NE 1/4, Sec. 16, T-29 N, R. 5 E, Wayne County, near left bank on downstream side of pier of bridge on State Highway 34. 1.0 mile upstream from Clark Creek. 3.0 miles east of Patterson.
MAX FLOW	79,200 cfs 3/11/35 (gage height 30.70 feet), from rating curve extended above 55,000 cfs; maximum gage height, 31.0 ft. 4/14/45 (backwater from Wappapello Dam); Maximum stage known 33.8 ft (present datum) in 8/1915, from floodmarks (disc 100,000 cfs from rating curve ext abv 55000 cfs)
MIN FLOW	8 cfs on 8/28/36 to 9/1/36
AVG FLOW	52 years 1072 cfs
BANKFULL FLOW	14289 cfs (16.0 feet)
QUALITY OF RECORDS	Good: 1965, 1967, 1968 Fair: 1966, 1969, 1970-72
REMARKS	Poor records during periods of no gage heights on: 10/18/67 - 12/6/67 12/12/67 - 1/22/68 8/9/68 - 9/30/68 Simulation period of record: 10/67 - 9/72

TABLE IV

SUMMARY RIVER GAGE DATA - LAUREL, MS

BASIN: TALLAHALA CREEK at LAUREL, MS

GAGE NUMBER	02473500
GAGE TYPE	Water-Stage Recorder - 1964 to present
GAGE ZERO	201.37 feet above MSL
DRAINAGE AREA	233 mi^2
PERIOD OF RECORD	9/38 to present
HISTORY OF GAGE LOCATION SINCE 1964	Lat 31°40'50", Long 89°06'55" in NE 1/4, ME 1/4, Sec. 8, T.8N., R.11W., St. Stephens meridian, Jones County. On right bank at downstream side of bridge on State Highway 15. 0.5 mile upstream from Gulf, Mobile and Ohio Railroad bridge. 0.5 mile southeast of city limits of Laurel.
MAX FLOW	23,300 cfs 4/14/1974 (Gage height, 23.38 feet from Floodmark): Maximum stage known since at least 1880, about 26 feet 12/9/1919. Flood in 4/1900 reached a stage of about 24 feet from information by local residents.
MIN FLOW	1.8 cfs 11/3/52, 10/31 and 11/1/63: Minimum Gage height, 1/21 ft. 10/31, 11/1/63.
AVG FLOW	36 Years 335 cfs
BANKFULL FLOW	1600 cfs (13.0 feet)
QUALITY OF RECORDS	Good: 1964, 1965, 1969, 1971-1972 Fair: 1966-1968 Poor: 1970
REMARKS	Poor records during periods of no gage heights on: 7/24/65 - 7/26/65 Simulation period of record: 10/64 - 9/72

TABLE V

SUMMARY RIVER GAGE DATA - COLLINS, MS

BASIN: LEAF RIVER Near COLLINS, MS

GAGE NUMBER	02472000
GAGE TYPE	Water Stage Recorder - 1964 to present
GAGE ZERO	197.48 above MSL
DRAINAGE AREA	752 mi^2
PERIOD OF RECORD	9/38 to present
HISTORY OF GAGE LOCATION SINCE 1964	Lat 31°42'25", Long 89°24'25", in NE 1/4 Sec. 33, T.9 N., R.14 W., St. Stephens meridian, Covington County. On right Bank at Downstream side of bridge on U. S. Highway 84. 9.5 miles northeast of Collins, at mile 114.5 from Mouth.
MAX FLOW	54,200 cfs 4/14/74 (gage height 32.6 ft. from Floodmark); Flood in 4/1856 reached stage about 33 ft., and the flood in 4/1900 reached stage of 32 feet, from information by local residents.
MIN FLOW	55 cfs on 8/28-30/1957
AVG FLOW	36 years 1,052 cfs
BANKFULL FLOW	6171 cfs (14.0 feet)
QUALITY OF RECORDS	Good: 1969, 1970, 1972 Fair: 1965-68, 1971 (See Below)
REMARKS	Poor records during periods of no gage heights on: 1/16/65 - 1/22/65 2/2/65 - 2/12/65 12/10/71 - 5/3/72 Simulation period of record: 10/64 - 9/72

TABLE VI

SUMMARY RIVER GAGE DATA - EDINBURG, MS

BASIN: PEARL RIVER at EDINBURG, MS

GAGE NUMBER	02482000
GAGE TYPE	Water Stage Recorder - 1964 to present
GAGE ZERO	341.67 feet above MSL
DRAINAGE AREA	898 mi^2
PERIOD OF RECORD	8/28 to present. Gage height records collected in same vicinity since 1908 con-in reports of National Weather Service.
HISTORY OF GAGE LOCATION SINCE 1964	Lat 32°47'55", Long 89°21'10", in SW 1/4, SW 1/4, Sec. 13, T.11N., R.93., Choctaw meridian, Leake County. On Right bank 20 feet downstream from bridge on State Highway 16 at Edinburg. At mile 387.5 from Mouth.
MAX FLOW	31,400 cfs 3/8/1935: Maximum gage height, 26.72 feet, 4/15/1974. The flood in 3/1902 reached a stage of 29.0 feet from reports of National Weather Service.
MIN FLOW	1.7 cfs on 10/5/1954 (gage height, 1.02 feet)
AVG FLOW	46 Years 1,080 cfs
BANKFULL FLOW	5230 cfs (20.0 feet)
QUALITY OF RECORDS	Good: 1964 - 1971 Fair: 1972
REMARKS	Simulation period of record: 10/64 - 9/72

TABLE VII

SUMMARY RIVER GAGE DATA - GLENMORA, LA

BASIN: CALCASIEU RIVER near GLENMORA, LA

GAGE NUMBER	08013000
GAGE TYPE	Water-Stage Recorder - 1964 to present
GAGE ZERO	110.77 feet above MSL
DRAINAGE AREA	499 mi^2
PERIOD OF RECORD	8/43 to present
HISTORY OF GAGE LOCATION SINCE 1964	Lat 30°59'45", Long 92°40'25", SE 1/4, SE 1/4, Sec. 4, T1S, R.3W, Louisiana Meridian, Rapides Parish. On right bank on downstream side of bridge on State Highway 113. 1.0 mile upstream from Prairie Branch. 4.6 miles northwest of Glenmora.
MAX FLOW	59,900 cfs (21.55 feet) on 5/19/53
MIN FLOW	15 cfs on 9/27, 9/28, 10/7-9/1954, 10/18/56
AVG FLOW	32 Years 728 cfs
BANKFULL FLOW	12,600 cfs (15.95 feet)
QUALITY OF RECORDS	Good: Except as listed below.
REMARKS	Records Fair during periods of no gage height on: 6/7/65 - 7/22/65 11/6/69 - 1/8/70 10/9/70 - 10/14/70 12/3/70 - 1/5/71 2/26/71 - 4/6/71 6/26/72 - 8/7/72 9/11/72 - 9/30/72 Simulation period or record: 10/64 - 9/72

TABLE VIII

SUMMARY RIVER GAGE DATA - OBERLIN, LA

BASIN: CALCASIEU RIVER near OBERLIN, LA

GAGE NUMBER	08013500
GAGE TYPE	Water-Stage Recorder - 1964 to present
GAGE ZERO	39.43 feet above MSL
DRAINAGE AREA	753 mi^2
PERIOD OF RECORD	8/22 to 1/25 and 9/38 to present
HISTORY OF GAGE LOCATION SINCE 1964	Lat 38°38'25", Long 92°48'50", NW 1/4, NE 1/4, Sec. 7, T.5S, R.4W, Allen Parish. Near right bank on downstream side of bridge on State Highway 26. 3.0 mile northwest of Oberlin. 15 mile upstream from Whisky Chitto Creek.
MAX FLOW	72,800 cfs (26.53 feet) on 5/19/53. Flood 6/1886 reached stage of between 22 feet and 23 feet, present datum.
MIN FLOW	30 cfs on 9/28-29/56 and 10/17-19/56. Min. gage height 1/68 ft. on 9/20-23/1970 and 7/20/71.
AVG FLOW	39 Years 1821 cfs.
BANKFULL FLOW	14,400 cfs (18.5 feet)
QUALITY OF RECORDS	Good: Except as listed below.
REMARKS	Fair records during periods of no gage heights on: 1/2/65 - 1/5/65 1/13/65 - 1/26/65 2/18/65 - 2/23/65 5/1/65 - 5/25/65 Simulation period of record: 10/64 - 9/72.

The average fall is about three feet per mile for the reach above Fayetteville. The minimum elevation within the basin is about 640 feet MSL near Fayetteville, while the maximum elevation is near 2,000 feet MSL along the upper reaches of the basin. Width of the flood plain along the river length of 110 miles varies considerably due to rough topographical features.

Spring River - Imboden, Arkansas

The Spring River at Imboden, Arkansas, has a drainage area of 1162 square miles. The headquarters of the river originate in South Central Missouri and flow southeastward to the gage, located near the community of Imboden, Arkansas. The basin is totally within the Arkansas Valley, a synclinal feature lying north of and parallel to the Quachita Mountains, underlain by Pennsylvania Sandstone and Shale.

The surface drainage pattern is well defined and has been created mostly by stream meandering and side hill drainage. The Spring River flood plain ranges from a few hundred feet to about 0.75 mile wide. The Channel slopes approximately nine feet per mile--a rather steep slope, indeed. The ground elevations range from 300 feet MSL at the lower end of the basin near the gage to 1100 feet MSL in the upper watershed reaches. The total length of the river is about 90 miles.

St. Francis River - Patterson, Missouri

The St. Francis River at Patterson, Missouri, has a drainage area of 956 square miles, and headwaters in southeastern Missouri near the town of Farmington. The river flows generally southward to the Patterson gage. The basin is located within the Mississippi Alluvial

Plain, which is a flat to slightly undulating surface underlain by Pleistocene and recent alluvial and terrace deposits. The stream flows through alluvial valleys consisting of 10 to 50 feet of silts and clays underlain by sand and gravels 30 to 150 feet thick. The river slopes about three feet per mile in the upper reaches and flattens to about 0.5 feet per mile along the lower end. The flood plain varies from about 300 feet up to a maximum of 1.25 miles in width. The basin is 30 miles wide at its maximum extent, with the ground varying from 390 feet MSL in the flood plain near Patterson to 1025 feet MSL along the drainage divide in the upper reaches of the basin. The total length of the river is nearly 69 miles.

Tallahala Creek - Laurel, Mississippi

Tallahala Creek at Laurel, Mississippi, drains an area of 233 squre miles. The river originates in southern Mississippi and flows southward to the gaging station at Laurel. The entire basin is located within the Southern Pine Hills district, which is a predominantly sandy terrain underlain by geological units of Oligocene, Miocene, Pliocene, and Quaternary ages. The highest watershed features are hills and ridges where blanket deposits, generally referred to as the Citronelle Formation, have not been completely eroded. The well defined surface drainage pattern has been created by stream meander and side hill drains. The Tallahala Creek flood plain ranges from 0.5 to 1.0 mile wide; the channel slopes approximately 5.5 feet per mile. Ground elevations vary from 200 feet above mean sea level in the flood plain to 625 feet MSL in the upper reaches of the basin. The total length of river is approximately 75 miles.

Leaf River - Collins, Mississippi

The Leaf River at Collins, Mississippi, has a drainage area of 752 square miles. The headwaters of the Leaf originate in southern Mississippi and flow southward to the gage location. The entire basin is located in the Southern Pine Hills Physiographic district, which is a predominantly sandy terrain underlain by geological units. The highest elevations in the basin are hills and ridges where blanket deposits, generally referred to as the Citronelle Formation, exist. The drainage pattern has been developed generally from stream meander and side hill drains. The Leaf River flood plain ranges from about 0.5 mile wide up to nearly 1.5 miles wide. The Channel slopes approximately five feet per mile. The ground elevations range from 215 feet MSL in the flood plain near the gage to 500 feet MSL along the upper drainage divide. The total length of river is near 48 miles.

Pearl River - Edinburg, Mississippi

The Pearl River at Edinburg, Mississippi, has a drainage area of 898 square miles with the headwaters originating in central Mississippi. The river flows generally southward for a few miles and then turns 90 degrees and flows west to the river gage at Edinburg. The basin is located within the Jackson and the Southern Pine Hills Groups of physiographic features. In central Mississippi the outcrop of the Jackson Group forms the Jackson Prairie, a district characterized by gently rolling terrain developed on nearly impermeable clay. The watershed southern drainage, however, is in the Southern Pine Hills district, a predominantly sandy terrain underlain by geologic units. The highest areas in the district are hills and ridges where blanket deposits generally referred to as the Citronelle Formation have not been completely eroded. The surface drainage pattern is made up of numerous tributaries feeding the main river to form a spider effect. The Pearl River floodplain ranges from about 0.25 mile wide to about 1.5 miles in width. The Channel slopes average 3.5 feet per mile. Ground elevations range from 370 feet in the flood plain near Edinburg to 610 feet MSL in the upper reaches of the basin. The total length of river is approximately 53 miles.

Calcasieu River - Glenmora, Louisiana, and Oberlin, Louisiana

The Calcasieu River rises in the pine hills of northwestern Louisiana near Leesville at an elevation of 390 feet. The river flows initially in a southeasterly direction for about ten miles, and then takes a 45 degree turn and flows easterly for about 20 miles. The stream at this point again changes course toward the southeast and continues to flow in this direction until a tributary, Cypress Bayou, joins it near Hineston, Louisiana. The bed of the river drops from an elevation 390 feet at its origin to elevation 150 feet by the time it meets Cypress Bayou. Beyond this, the river flows with a gentler slope south toward the Gulf of Mexico. The river bed drops another 70 feet by the time it reaches Oakdale, a distance of 76 miles from the headwaters. The total fall of the Calcasieu River from its headwaters to the lower reaches is about 320 feet, for an average fall of approximately four feet per mile. However, the slope is about seven feet per mile the first 30 miles from its source.

The basin is made up of two geologic areas: the upper area within the East Texas Timber Belt and the lower area within the Pine Flats. The East Texas Timber Belt is a district developed on the sand and clay strata of the Claiborne and Jackson Groups and, in some areas, overlaying Quaternary deposits. The Pine Flats are low, gently sloping to nearly flat terrain underlain by Quaternary deposits.

The watershed to Oberlin is about 75 miles long and up to 15 miles wide. The basin divide on the west and north is only a serial of low hills and ridges. In the lower reaches of the basin, the divides between the Calcasieu Basin and adjacent watersheds are very low and barely distinguishable. The watershed may best be described as consisting of two parts: a high land plateau of pine forest with an average elevation of 250 feet, and a lower flat, agricultural land with an average elevation of 120 feet.

Except for the headwater areas, the Calcasieu River flows through a very meandering channel in a flood plain varying from a few hundred feet to nearly one mile in width. Along the upper reaches of the basin the river meanders so much that it is made up of several interwoven channels "criss-crossing" one another. The total drainage area above Oberlin is 723 square miles. The local area catchment, also modeled in this report, is the drainage below Glenmora.

Isochronal Analyses

The concept of "building" the headwater or ungaged local area hydrograph at a flow point by routing runoff over the contributing area above the river gage is not new. Clark (30) and Kohler (31) addressed the runoff distribution problem by assuming an inflow hydrograph that is derived by lagging runoff over various basin zones in proportion to the travel time above the gaging station. To the gage inflow there is then applied storage routing, resulting in a basin outflow hydrograph. A channel response function in the form of a "time-delay histogram" allows one to fabricate an inflow hydrograph which has channel lag built into it but not storage attenuation. A time-delay or time-area histogram requires the division of the watershed into "N" sub-areas where each area is defined as a function of drainage time. Boundaries of sub-areas are known as isochrones, which may represent "X" minutes or hour intervals depending on the size of the basin. Since the concept of the time-delay histogram and its relationship to the distributed model is covered in detail in Chapter V, little need be said about its use at this time. Suffice it to say that an isochronal analysis, as discussed in the following paragraph, was completed in order to locate travel time zones (sub-areas) across each of the eight research watersheds and compute time-delay histograms. Once the isochrone positions are so identified, zones may be selected over which one has the option of computing individual mean zone precipitation (MZP) and maintaining individual zone soil moisture accounting. The methodology is discussed next.

A six-hour isochronal analysis was performed for each catchment through a four-step procedure:

1. Estimate an average water speed along the entire stream system that would occur during flood flow. This information was approximated by measuring main stem watercourse length and determining unit hydrograph time base. Then main stem length divided by unit graph (UG) time base equals average speed. For example, given a watercourse length of

20 miles and a UG time base of ten hours, the average watercourse speed computes to be 2 MPH.

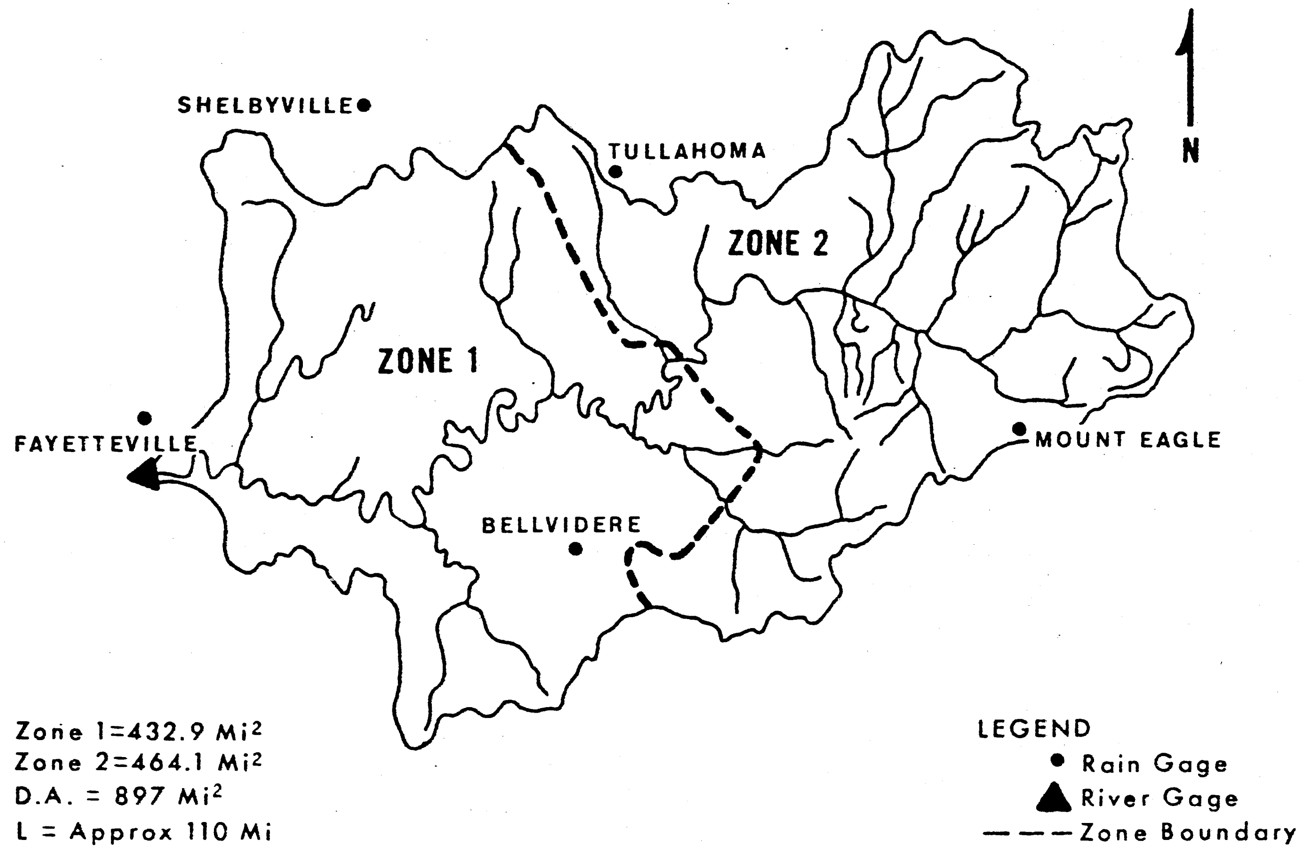
2. Using water speed computed in step 1, compute distance traveled in six hours. For the example case, this comes out to be 12 miles.

3. Using distance determined in step 2, mark off a topographical map of the watershed distances up main stem and all tributaries in 12-mile (6-hour) increments (distances measured above river gage).

4. Connect all points of equal distance above river gage; thus, the 6-hour isochrone positions are determined.

More sophisticated isochronal analysis techniques are reported in the literature (32)(33) that make use of basin slopes and concentration time, but were rejected for use in this study due to the fact that the time-delay histogram is subject to change during the calibration/model fitting process. A simplified procedure which determines isochrone areas by backrouting a UG was also rejected, as prior experience dictates that a time-delay histogram so derived may be in considerable error.

To compute the inflow time-delay histogram, one need only to then measure (planimeter) the area between isochrones, which represent area drained in 6-hour increements, and normalize by dividing each sub-area by the total drainage area. To account for the spatial variation of rainfall by assigning zones (sub-areas) for mean areal precipitation computations (MZP), the rain gage network was examined to see whether or not a two or three zone breakdown could be justified. Also considered at this time to assist in zone positioning were the physiographical and soil features of the basin. Figures 1 through 8 display for each test watershed the location of rain gages, final zone delineation, and

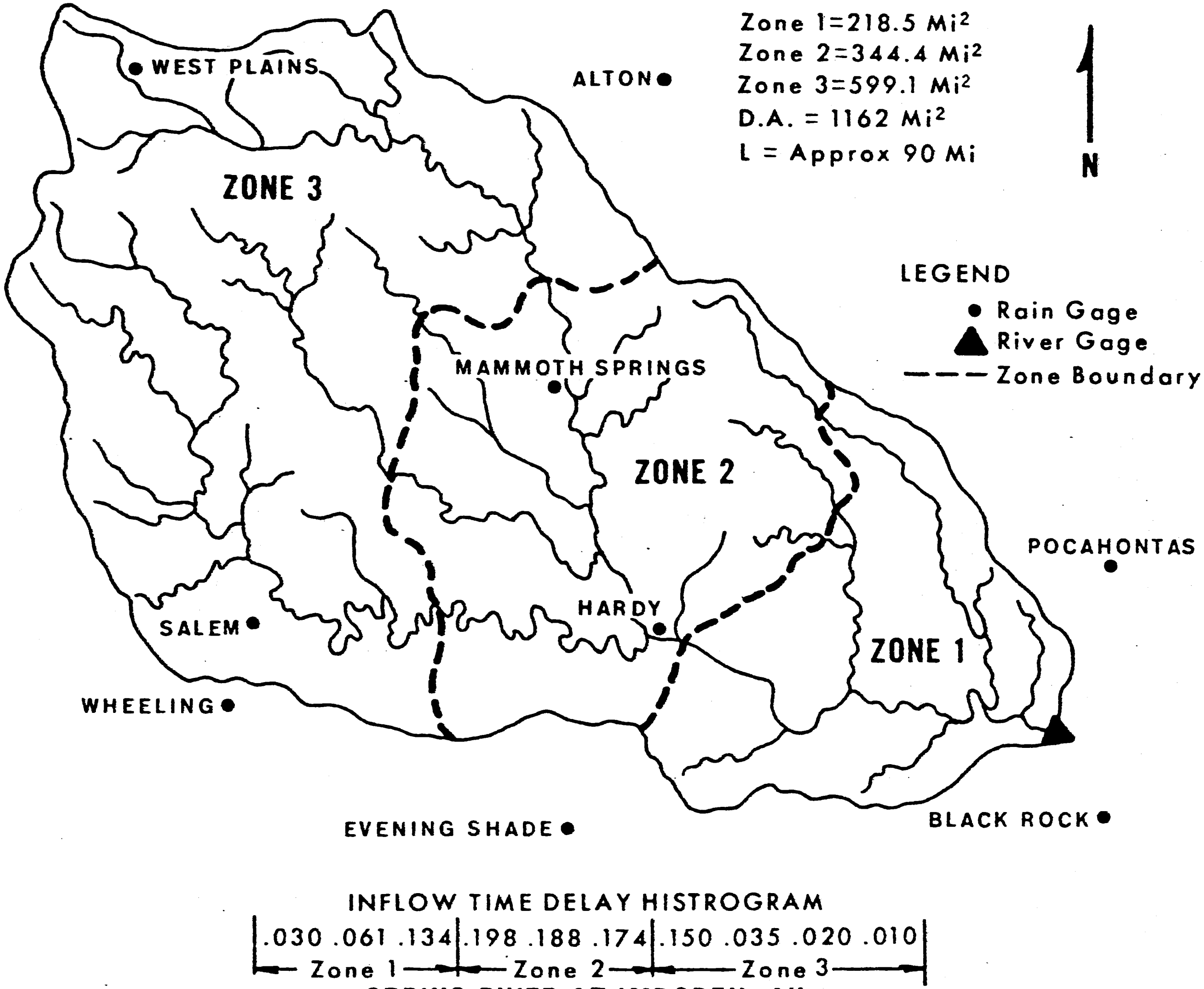


INFLOW TIME DELAY HISTROGRAM

.026	.055	.064	.048	.070	.129	.080	.077	.085	.092	.066	.077	.074	.057
Zone 1								Zone 2					

ELK RIVER AT FAYETTEVILLE, TN.

Figure 1. Fayetteville Basin Map, Zone Delineation, and Precipitation Gage Network



SPRING RIVER AT IMBODEN, AK.

Figure 2. Imboden Basin Map, Zone Delineation, and Precipitation Gage Network

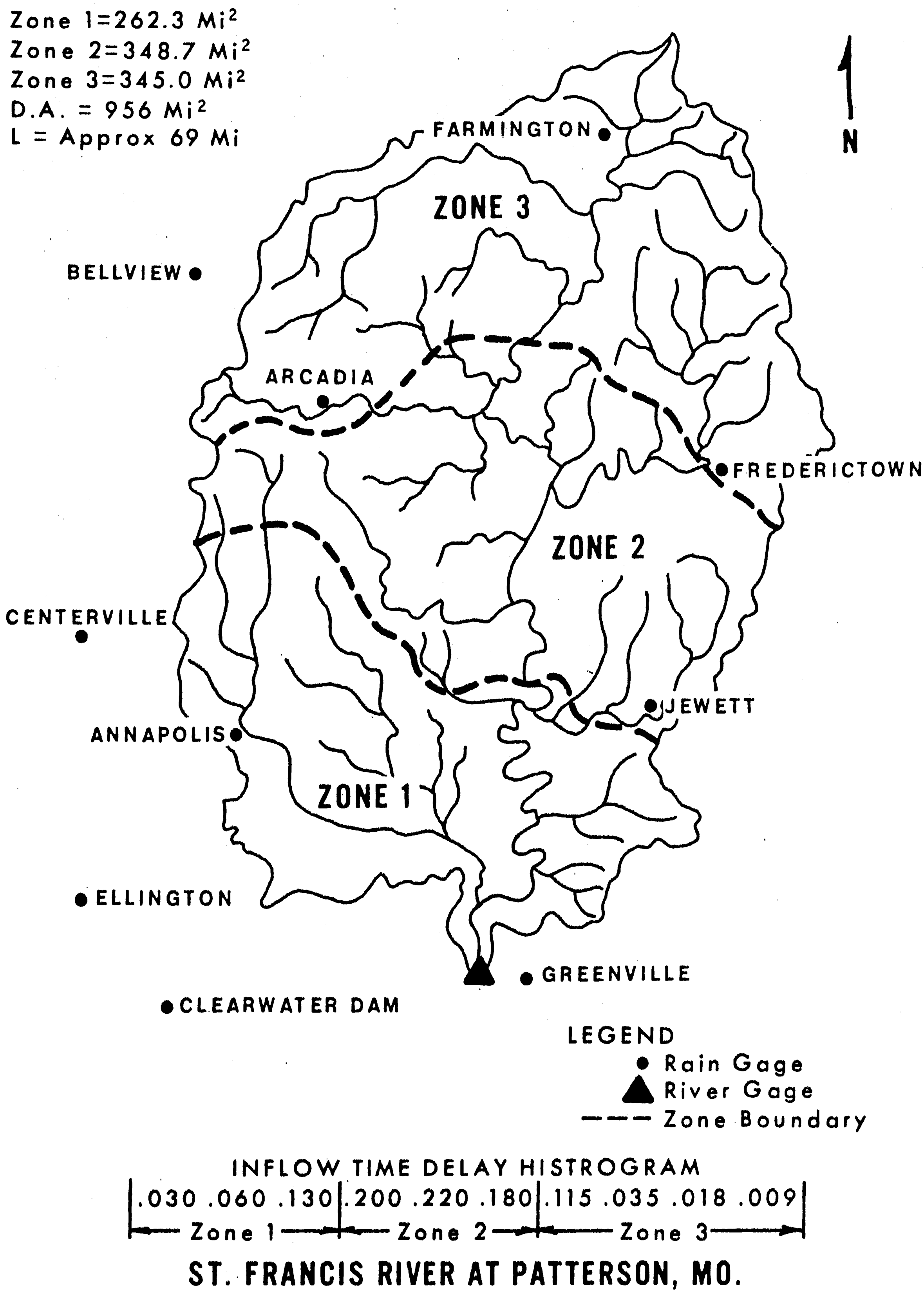


Figure 3. Patterson Basin Map, Zone Delineation, and Precipitation Gage Network

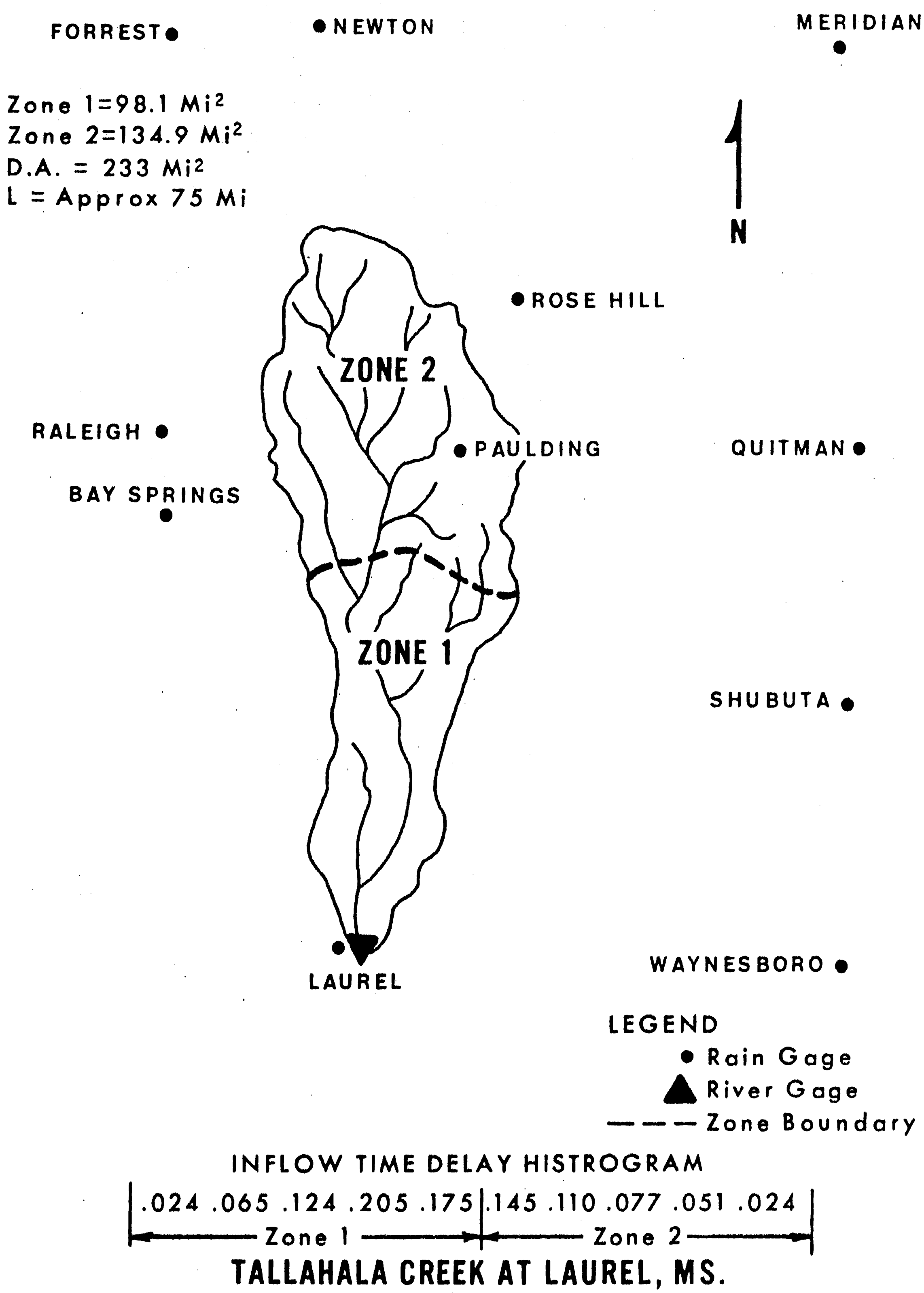


Figure 4. Laurel Basin Map, Zone Delineation, and Precipitation Gage Network

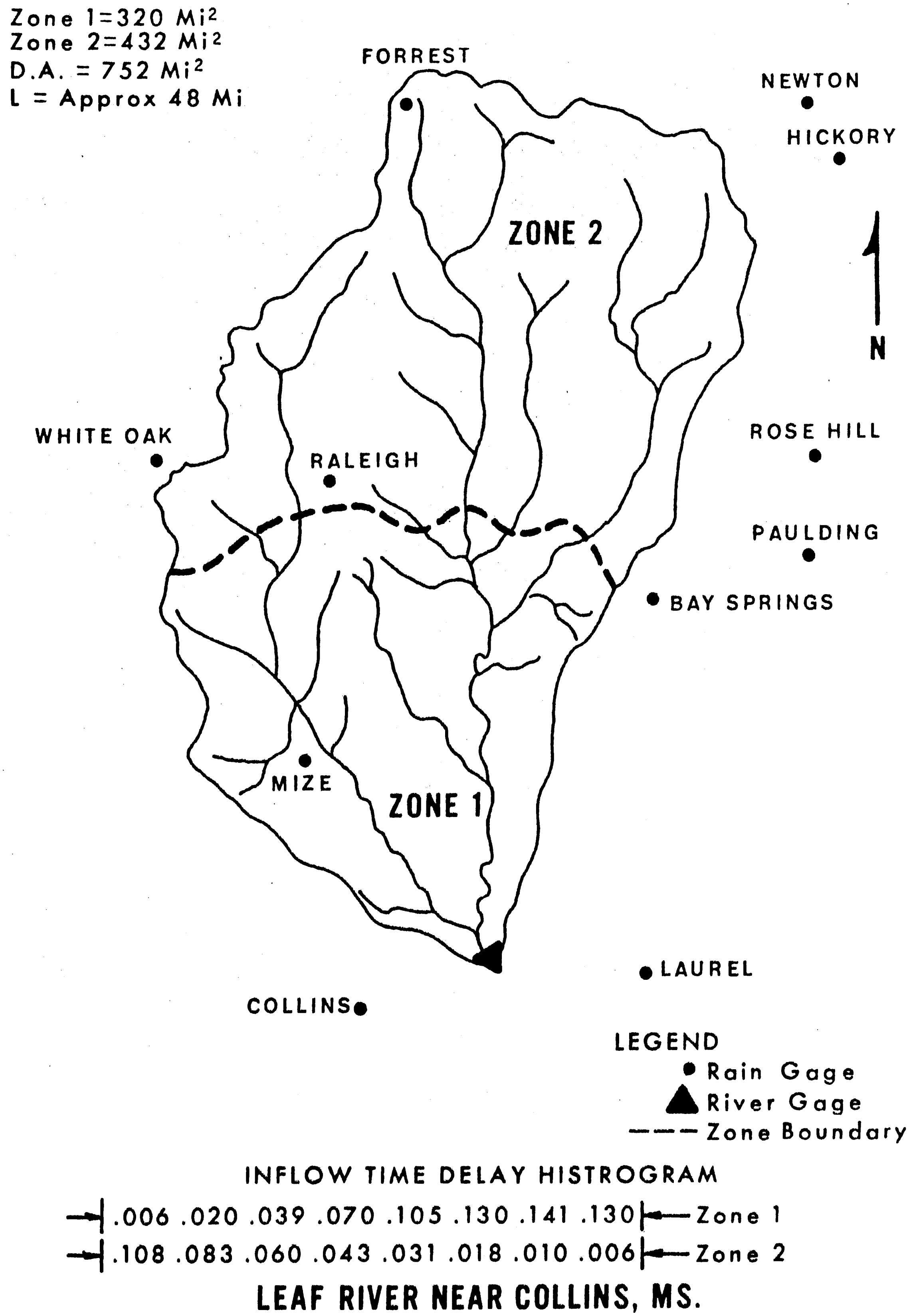


Figure 5. Collins Basin Map, Zone Delineation, and Precipitation Gage Network

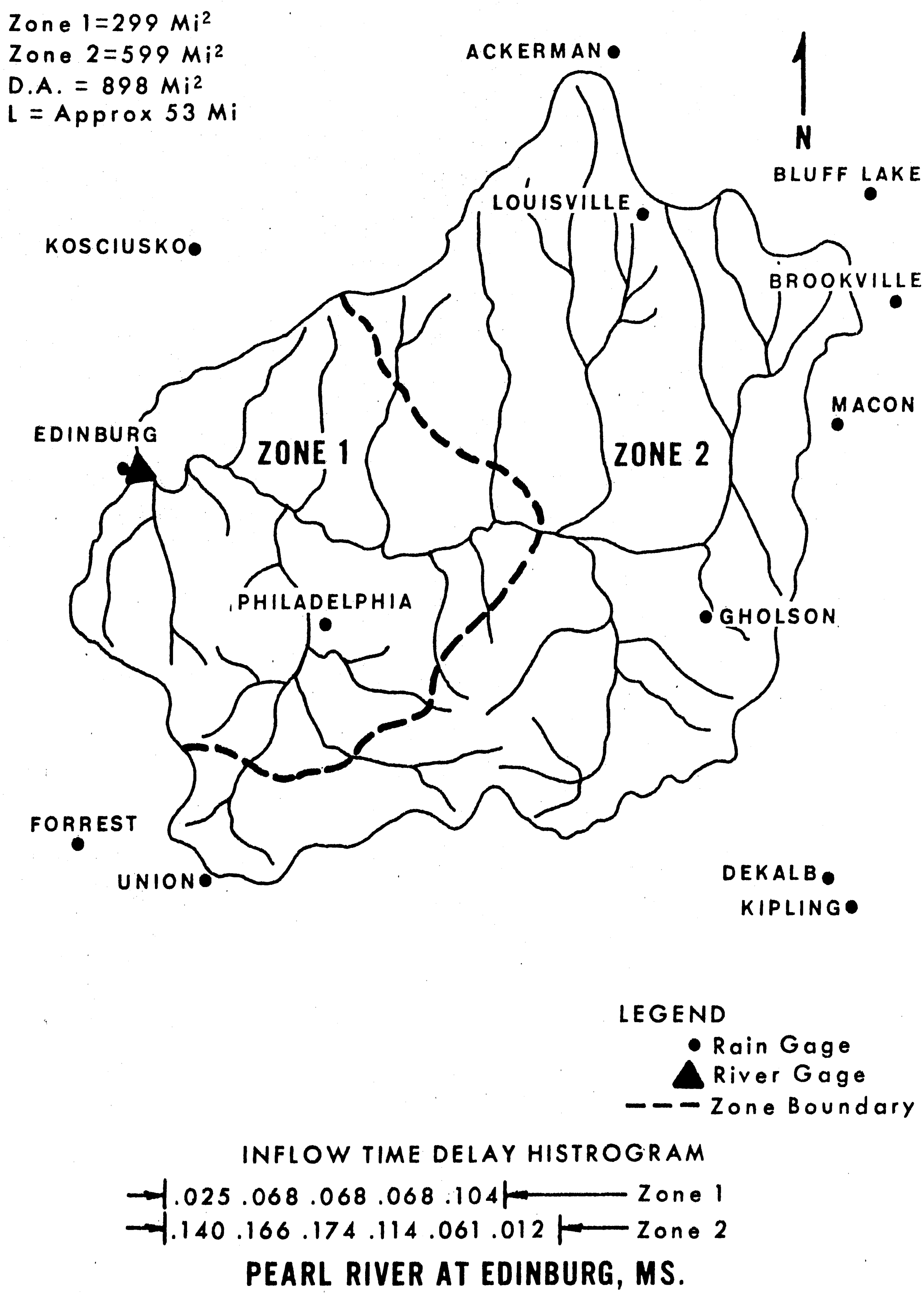
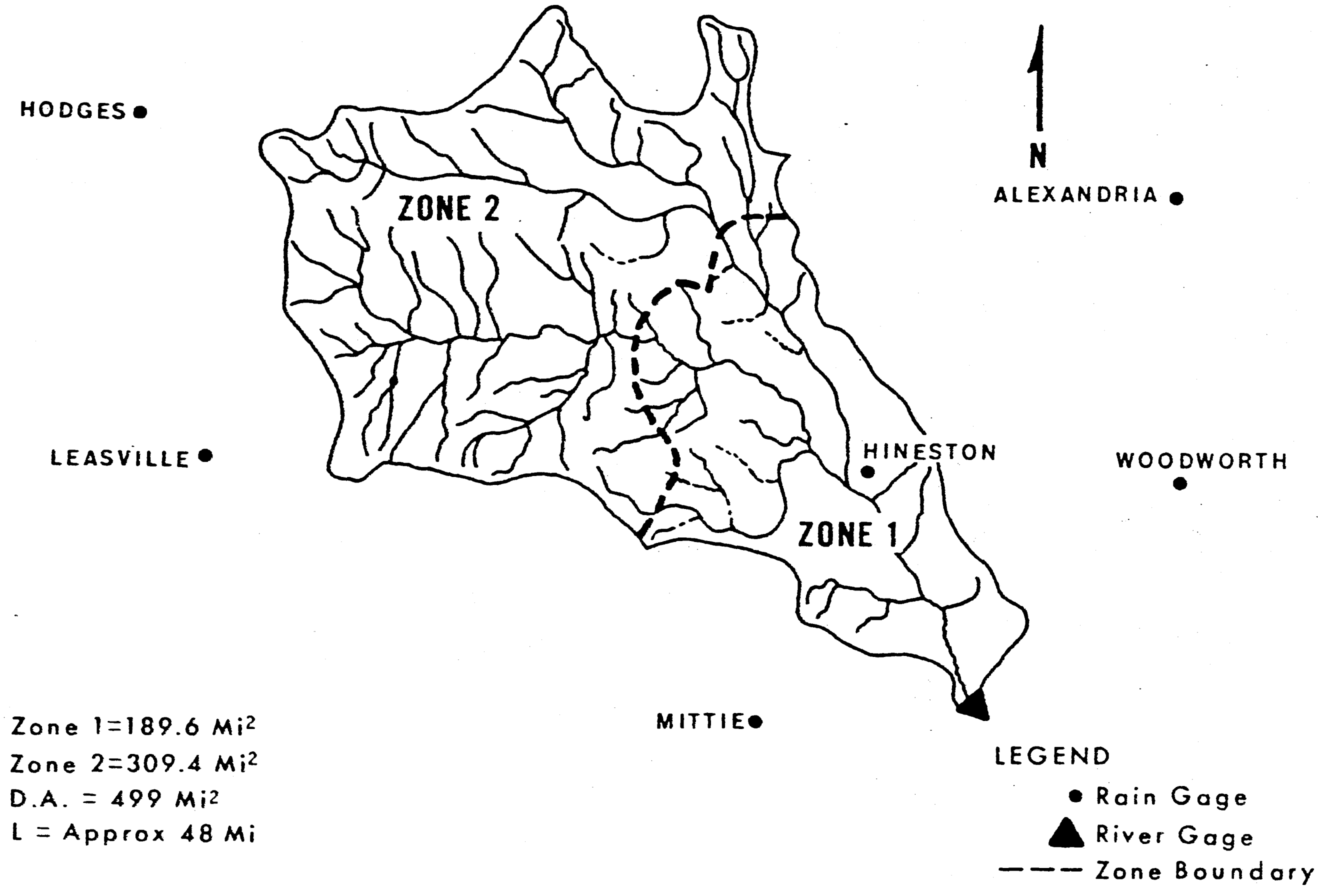


Figure 6. Edinburg Basin Map, Zone Delineation, and Precipitation Gage Network

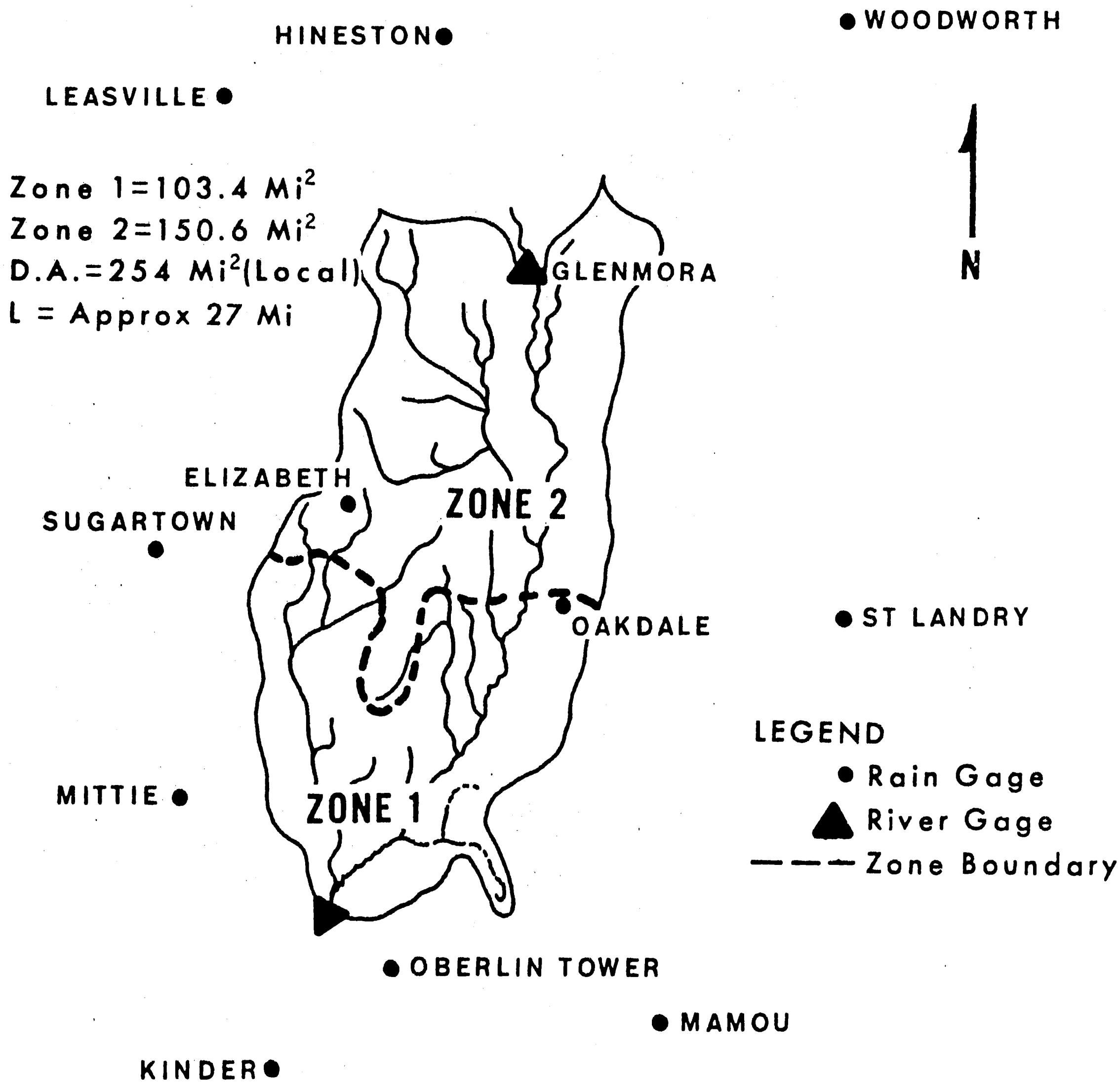


INFLOW TIME DELAY HISTROGRAM

.040	.064	.073	.090	.113	.148	.192	.196	.073	.011
Zone 1					Zone 2				

CALCASIEU RIVER AT GLENMORA, LA.

Figure 7. Glenmora Basin Map, Zone Delineation, and Precipitation Gage Network



INFLOW TIME DELAY HISTROGRAM

(Local area)

.073	.111	.224	.217	.211	.164
Zone 1			Zone 2		

(Total area)

.024	.037	.072	.074	.070	.054	.027	.049	.043	.060	.076
Zone 1			Zone 2			Zone 3				

.099	.128	.130	.049	.008
Zone 4				

CALCASIEU RIVER NEAR OBERLIN, LA.

Figure 8. Oberlin Basin Map, Zone Delineation, and Precipitation Gage Network

computed inflow time-delay histogram. The total drainage area for Oberlin consists of the local area (Figure 8) plus Glenmora drainage (Figure 7). When simulating Oberlin, however, the Glenmora observed hydrograph is routed downstream to the Oberlin gage, so that the catchment model then applies to only the local area. The total area time-delay histogram is included in Figure 8 solely for the purpose of illustrating local versus total area histogram differences. The zone demarcation line for all eight basins always falls along an isochrone. It should be pointed out that the location of rain gages on the maps is not to exact scale. Also, several gages used to estimate missing basin network precipitation data (Chapter IV) are not shown due to their distance from the watershed. And finally, mention should be made that a few precipitation stations carrying zero weight, when computing areal mean rainfall (Chapter IV), are shown on the maps but not noted in the station weight tables (Chapter IV) for the Edinburg and Oberlin watersheds.

CHAPTER IV

DATA CONSIDERATIONS AND REDUCTION PROCEDURES

Introduction

This chapter summarizes the data reduction techniques utilized by the author at the Lower Mississippi River Forecast Center to establish model calibration and research data files on the UNIVAC 1108 3G system. The computer is located at the NASA Slidell Computer Complex. Vast amounts of hydrologic data are required to perform model research on any significant scale, and thus it becomes necessary to have the means for efficient data reduction and retrieval through the use of computerized data manipulation and processing routines. In the final processed form, data are stored on magnetic tape for use by the hydrologic model. These input data tapes are blocked by monthly records, with each type of data in a specific sequence. A standard month length of 31 days is used with 124 values for six-hour data and 31 values for daily data. Data values are in binary code with the data field on tape "zeroed" for the excess days during months with less than 31 days. The sequence in which each data type is entered for each monthly block is:

Sequence Number	Tape	Type of Data
1	1	Mean basin/zone six-hour precipitation (MBP/MZP)
2	1	Daily potential evapotranspiration (PE)
3	1	Mean daily streamflow (MDF)
4	2	Instantaneous (six-hour) streamflow (6 HRQ)

Even when sufficient time and computer resources are available, the mass processing and reduction of hydrologic data is a complex and difficult job. Any conceptual, parametric hydrologic model is data bound. Linsley (10) stated there is no point in trying to make a simulation model with greater accuracy than the stream gaging. His comment can be expanded to include precipitation, and to a lesser extent, potential evapotranspiration. For study purposes, the hydrologic data base must be the best obtainable. Editing of data must be done in a sytematic day-to-day fashion. Figure 9 illustrates from left to right the data processing steps to establish model calibration/research files.

Precipitation

Hourly and daily precipitation raw data on magnetic tape were retrieved from the National Climatic Center (NCC) Environmental Data Service (EDS), NOAA, Asheville, North Carolina. Daily observational data tapes received from NCC included not only once-daily (24-hour) precipitation values, but also additional station climatic data such as max-min air temperature and snow on ground. All raw data were ordered by states, and then through multi-processing steps, individual station hourly rainfall and daily rainfall values were extracted to complete the basic station precipitation file for each watershed.

Estimation Theory

The extraction of hydrologic intelligence from precipitation data requires knowledge of its variation over a watershed. Since precipitation is normally measured as a point value, and since the rain gage network is seldom dense, one must estimate the rainfall depth at

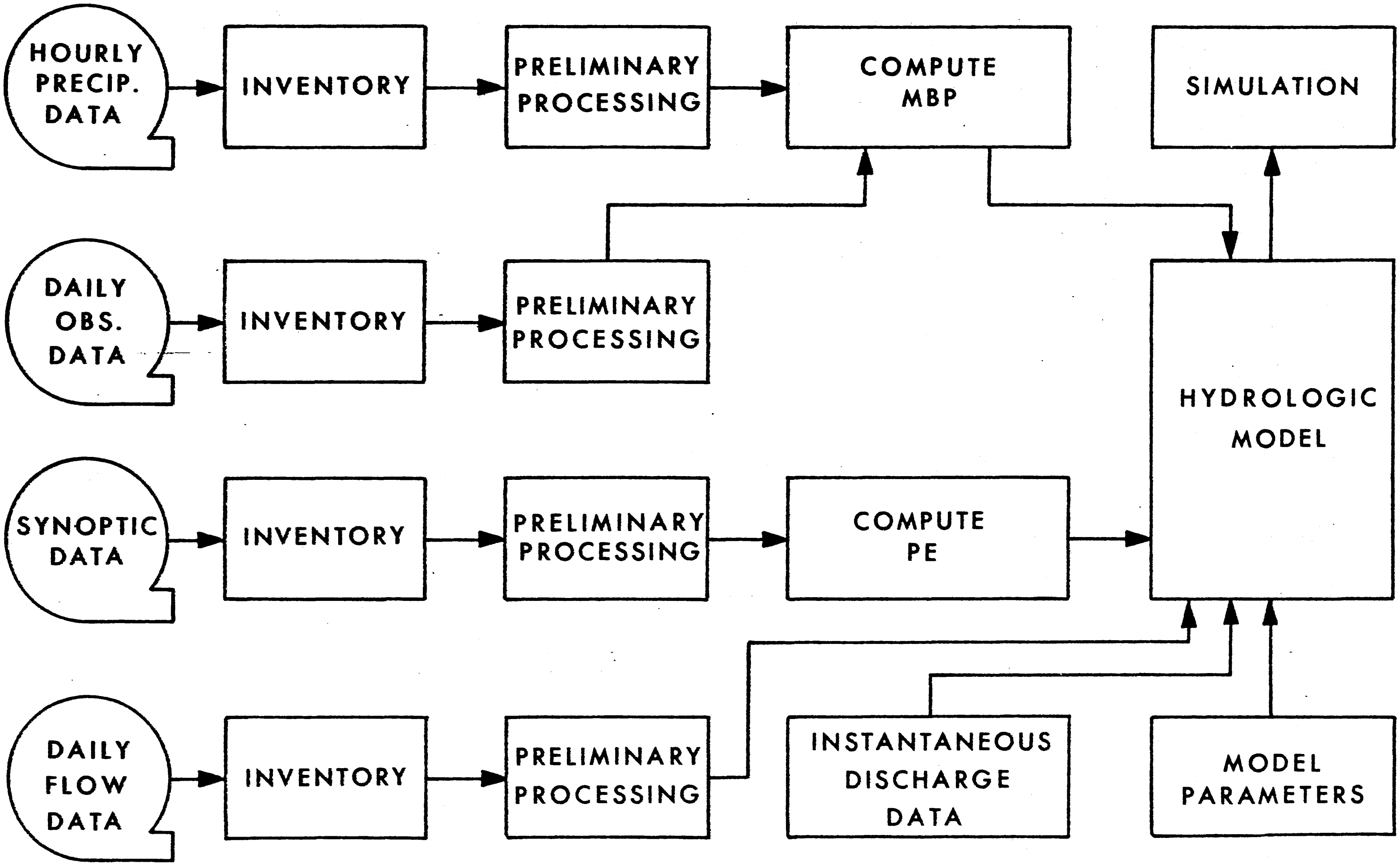


Figure 9. Data Processing Steps

various locations across the catchment from known precipitation reports. Any method of areal analysis, for example, isohyets, Thiessen weights, or grid point weights involves, implicitly or explicitly, inferences concerning the depth of rainfall at all points over the basin. The theory of estimation ($1/\text{distance}^2$) utilized in mean areal precipitation computation can be attributed to Mr. Walter J. Sittner (23), as discussed in NOAA Tech Memo NWS Hydro-14 (24). The procedure to be described is an objective formulation that produces an estimate of the rainfall at a point as a function of that at surrounding points, and is taken directly from Hydro-14. The method is the result of a great deal of unpublished development and experimentation over many years, and has been verified on both an empirical and theoretical basis. Only the mechanics of the method will be discussed.

Let a point X be a location on a watershed map where it is desired to estimate precipitation. North-South and East-West lines drawn through point X divide the surrounding area into four quadrants, numbered I through IV, counter-clockwise from the northeast. Figure 10 illustrates the procedure. Let points A, B, C, and D be the four points closest to X in each quadrant where rainfall is known. The estimate of rainfall at X is now computed as a weighted average of that at the other four points (A, B, C, D). The weight is equal to the reciprocal of the square of the distance ($1/d^2$) from point X to the known rainfall point. If there is no known precipitation in some of the quadrants, only the quadrants with precipitation are used.

The equation that estimates precipitation may be formulated as follows:

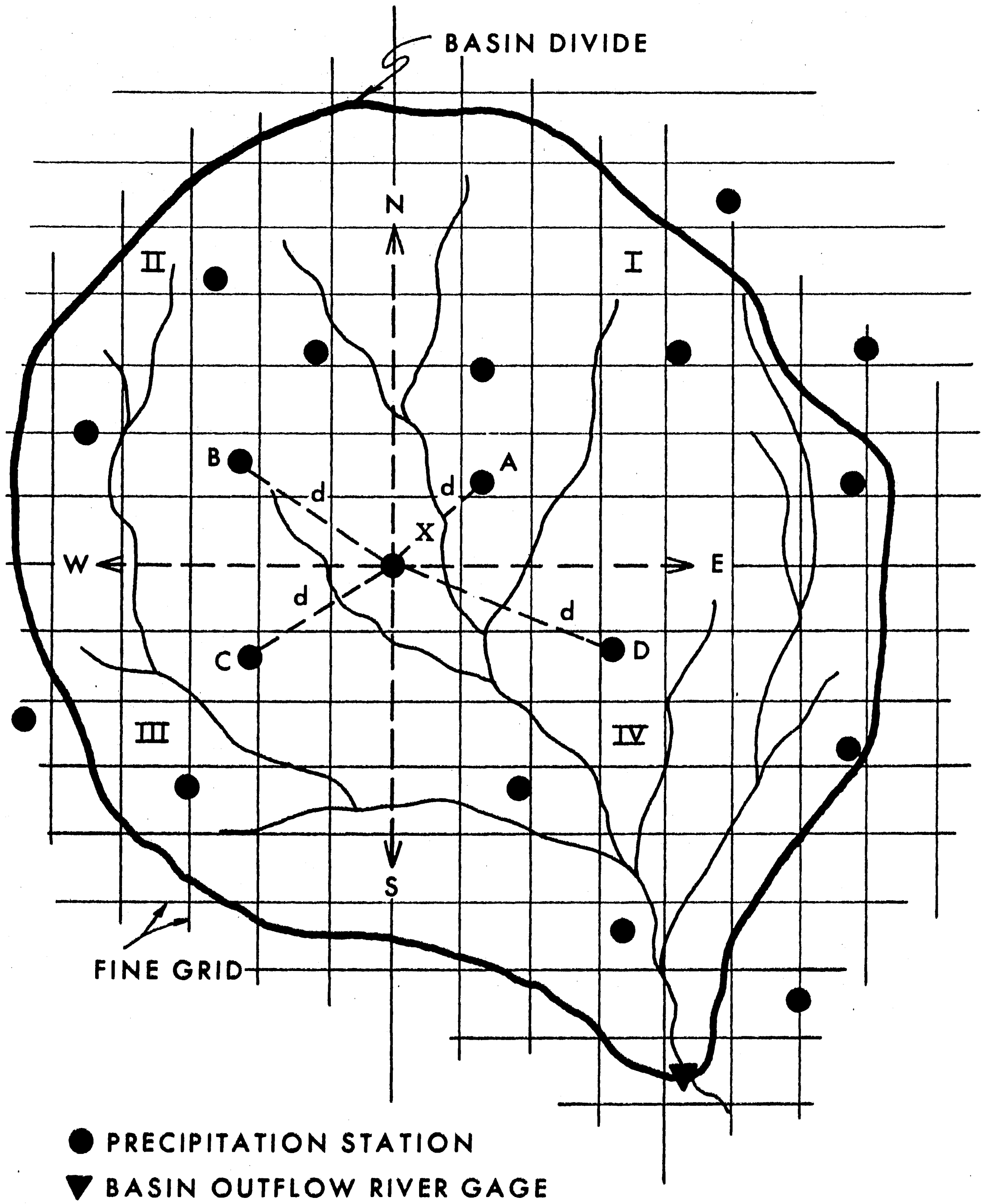


Figure 10. Point Rainfall Estimation Diagram

$$P_x = \frac{\sum_{1}^{\eta} P_\eta \cdot W_\eta}{\sum_{1}^{\eta} W_\eta} \qquad (4.1)$$

where

P_x = precipitation to be estimated at any point x

P_η = known precipitation at point closest to point x in each quadrant

W_η = $1/d^2$ = weighting factor where d is the distance from point x to known precipitation point in each quadrant

A variation of the method recognizes as a special case the situation where known precipitation points are found in only two quadrants and those two are adjacent; that is, I and II, II and III, III and IV, or IV and I. In this case, the estimate is given as ΣPW rather than $\Sigma PW/\Sigma W$. This has the effect of reducing estimates to zero as the points move from a precipitation area toward an area of no reports. This is probably the most logical treatment for this indeterminate and rather ununsual situation [source (24) p. 3-3]. The estimating technique described can never result in a point estimate that is greater than the largest amount observed or less than the smallest.

The basic estimating method can be used in a number of ways. The precipitation at network stations which fail to report in a particular event can be estimated. After the hourly and daily precipitation data has been extracted for a watershed, a computer program searches the hourly data to estimate missing periods of record and distribute periods for which only an accumulation value is available. The algorithm for estimating missing or accumulative hourly precipitation data is as follows [source (24), p. 3-11]:

$$A_x = \frac{\sum_{i=\eta}^{i=\eta}\left[A_i \cdot \frac{N_x}{N_i} \cdot \frac{1}{\left(d_{i,x}\right)^2}\right]}{\sum_{i=\eta}^{i=\eta} \frac{1}{\left(d_{i,x}\right)^2}} \tag{4.2}$$

where

A_x = hourly precipitation at the station being estimated

i = station being used as an estimator

η = number of estimators

A_i = hourly precipitation at the estimator station

N_x = monthly characteristic precipitation at the station being estimated (default = 1)

N_i = monthly characteristic precipitation at the estimator station (default = 1)

$d_{i,x}$ = distance from the station being estimated to the estimator station

If only an accumulation value is given, the hourly value is computed by use of the following equation:

$$A_x = \frac{\sum_{i=\eta}^{i=\eta}\left[A_i \cdot \frac{T_x}{T_i} \cdot \frac{1}{\left(d_{i,x}\right)^2}\right]}{\sum_{i=\eta}^{i=\eta} \frac{1}{\left(d_{i,x}\right)^2}} \tag{4.3}$$

where

T_x = accumulative amount at the station being distributed

T_i = total precipitation amount for the period of missing time distribution at the station being used to estimate the distribution

Equations (4.2) and (4.3) will handle the general case of missing data or accumulative data. For special cases, the following rules apply: If no valid estimator station is available, the hourly precipitation for that hour is set to zero and a message printed. If missing time distribution extends more than two days into the succeeding month, then the entire period is set to missing data and a message printed. The missing data period is again estimated using equation (4.2). If no station can be found to estimate a period of missing time distribution, then the accumulated amount is left in the last hour and again a message is printed.

At this point in data reduction, all hourly precipitation stations have a complete record free of missing or accumulative hourly amounts. Next, the daily precipitation is converted into hourly, month by month, by using the hourly precipitation stations to determine distribution of the daily values. Converting daily precipitation into hourly is a two-pass operation. On the first pass, daily precipitation observations are distributed but missing data are ignored. Equation (4.3) is used to distribute the daily observations, where T_x is now the daily precipitation observation and T_i is the total precipitation since the last daily observation at the hourly station being used to estimate the daily amount. Once the daily amount is estimated, it is distributed as in pass one. The reason for a second pass is so that not only can hourly precipitation stations be used to estimate the missing daily amount, but so that the amount from a daily station will be used if it is the closest station, in a particular quadrant, to the station being estimated. In this case, A_x in equation (4.2) is now the daily precipitation since the last daily observation at the hourly or daily station used as an estimator. For special cases the following rules apply: If no station can be found to distribute a daily observation, then the total amount is left in the hour of the time of observation and a message is printed. If missing time distribution extends more than two days into the succeeding month, then the entire period is set to missing data and an appropriate message printed. If no valid estimator station is available for a missing daily amount, the daily amount is set to zero and again a message is printed. At this point in the program, all hourly <u>and</u> daily stations have continuous <u>hourly</u> records free of missing or accumulative amounts.

Computation of Mean Basin/Mean Zone Precipitation

The estimating procedure so far has been applied to the analysis of an actual event in which precipitation amounts are the variable. Using the same concepts as discussed in Hydro-14, it is possible to compute a set of <u>station weights</u>, similar to Thiessen weights, which can be used to compute areal rainfall averages. Consider a basin covered with a fine grid, as shown in Figure 10. For a particular precipitation event, the estimating procedure described could be used to compute the rainfall at each grid point (grid line intersections) that falls within the basin. The arithmetic average of all of these grid point rainfall amounts would be the basin average rainfall. Station weights that will produce a basin average rainfall equal to the one computed in this manner are known as "grid point weights."

Station weights can be computed as follows: at each grid point falling within the basin, perform the estimating technique only as far as locating the four reference stations and computing the weights. Then normalize (adjust to unity) the weights, and assign each weight to the appropriate station. After this procedure has been repeated for each grid point, the total (sum) weight assigned to each station, after being normalized, is its grid point weight. Applying the resulting station weights, six-hour mean basin precipitation (MBP) or mean zone precipitation (MZP) for an area containing, say, five rain reporting stations, A, B, C, D, and X, would be computed as:

$$MBP = P_A \cdot W_A + P_B \cdot W_B + P_C \cdot W_C + P_D \cdot W_D + P_X \cdot W_X$$

where

P = rainfall for the six-hour period at a station

W = station weight

A special case exists where a station is located at the grid point. That individual station is simply given unit weight. Predetermined weights may be entered to compensate for topographical irregularities or unusual aspects such as present in mountains. The use of a finite number of grid points is an approximation to the exact solution where rainfall at every point over a watershed is known. The greater the number of grid points, the closer the approximation. Sensitivity analyses for this type of computation have indicated that adequate results will be obtained if 100 or more grid points fall within the basin.

Increasing the number of points above 100 refines results slightly, but beyond 150 points there is no perceptible change [source (24) p. 3-10].

Having determined station weights, as discussed above, for the test basin in question or for the zones within the basin, the final step was to compute mean basin (total area) precipitation and mean zone precipitation. Tables IX through XII display computed station (grid point) weights for the eight test basins used to basin-average or zone (sub-area) average precipitation values. Stations which reported hourly rainfall are noted by (R) and, of course, were used to distribute daily amounts. It is clear from these tables, as would be expected, that stations may take on quite different weights for a zone than for the basin total area, and the resulting mean zone precipitation can thus differ significantly from mean basin precipitation. Computation of mean areal precipitation was then simply accomplished by going through the entire rainfall file for each area (basin total area or zone area), multiplying the hourly precipitation by the station weight for all stations within the area, and summing these results to create a mean areal hourly precipitation sequence. The results were output in six-hour increments for use by the hydrologic model.

Potential Evapotranspiration

The concept of potential evapotranspiration (PE) has proved to be useful in present-day agriculture and hydrology. PE was first defined by Thorntwaite (25) as "water loss which will occur if at no time there is a deficiency of water in the soil for the use of vegetation." More recently, Van Bavel (27) wrote "Potential evapotranspiration can be defined for any situation in terms of the appropriate meteorological

TABLE IX

STATION WEIGHTS FOR IMBODEN AND FAYETTEVILLE

BASIN: IMBODEN, ARK

RAIN GAGE LOCATION		TOTAL AREA	ZONE 1	ZONE 2	ZONE 3
ALTON	(R)	.06	.00	.04	.09
CORNING	(R)	.00	.01	.00	.00
HARDY	(R)	.22	.35	.45	.03
WEST PLAINS	(R)	.18	.00	.01	.31
WHEELING	(R)	.03	.00	.01	.06
BLACK ROCK		.05	.38	.01	.00
EVENING SHADE		.03	.16	.02	.00
MAMMOTH SPRINGS		.22	.00	.38	.20
POCAHONTAS		.02	.10	.02	.00
SALEM		.19	.00	.06	.31

BASIN: FAYETTEVILLE, TN

RAIN GAGE LOCATION		TOTAL AREA	ZONE 1	ZONE 2	ZONE 3
BELLVIDERE	(R)	.31	.46	.17	
LEWISBURG EXP. ST.	(R)	.00	.01	.00	
FAYETTEVILLE		.12	.26	.00	
MOUNT EAGLE		.27	.01	.49	
SHELBYVILLE		.05	.08	.03	
TULLAHOMA		.25	.18	.31	

TABLE X

STATION WEIGHTS FOR PATTERSON AND EDINBURG

BASIN: PATTERSON, MO

RAIN GAGE LOCATION	TOTAL AREA	ZONE 1	ZONE 2	ZONE 3
BELLVIEW (R)	.06	.01	.02	.12
ELLINGTON (R)	.00	.00	.00	.00
FARMINGTON (R)	.16	.00	.02	.38
JEWETT (R)	.17	.23	.33	.01
POTOSI (R)	.01	.00	.00	.02
ANNAPOLIS	.15	.42	.10	.00
ARCADIA	.18	.04	.28	.19
CENTERVILLE	.01	.01	.00	.00
CLEARWATER DAM	.01	.04	.00	.00
FREDERICTOWN	.18	.00	.25	.28
GREENVILLE	.07	.25	.00	.00

BASIN: EDINBURG, MS

RAIN GAGE LOCATION	TOTAL AREA	ZONE 1	ZONE 2	ZONE 3
DEKALB (R)	.03	.01	.04	
FORREST (R)	.00	.01	.00	
ACKERMAN	.01	.00	.02	
BLUFF LAKE	.03	.00	.04	
BROOKVILLE	.00	.00	.00	
EDINBURG	.12	.32	.02	
GHOLSON	.24	.04	.34	
KIPLING	.01	.00	.02	
KOSCIUSKO	.01	.01	.00	
LOUISVILLE	.20	.02	.28	
PHILADELPHIA	.26	.50	.15	
UNION	.09	.09	.09	

TABLE XI

STATION WEIGHTS FOR COLLINS AND LAUREL

BASIN: COLLINS, MS

RAIN GAGE LOCATION		TOTAL AREA	ZONE 1	ZONE 2	ZONE 3
COLLINS	(R)	.02	.09	.03	
FORREST	(R)	.16	.00	.31	
RALEIGH	(R)	.21	.17	.20	
ROSE HILL	(R)	.02	.00	.04	
BAY SPRINGS		.11	.13	.07	
HICKORY		.00	.00	.00	
LAUREL		.01	.03	.00	
MIZE		.20	.45	.00	
NEWTON		.04	.00	.08	
PAULDING		.00	.00	.00	
WHITE OAK		.23	.13	.27	

BASIN: LAUREL, MS

RAIN GAGE LOCATION		TOTAL AREA	ZONE 1	ZONE 2	ZONE 3
FORREST	(R)	.00	.00	.01	
MERIDIAN	(R)	.00	.00	.00	
RALEIGH	(R)	.00	.00	.00	
ROSE HILL	(R)	.11	.01	.18	
SHUBUTA	(R)	.02	.04	.02	
BAY SPRINGS		.18	.21	.17	
LAUREL		.19	.42	.01	
NEWTON		.03	.00	.05	
PAULDING		.45	.28	.56	
QUITMAN		.00	.00	.00	
WAYNESBORO		.02	.04	.00	

TABLE XII

STATION WEIGHTS FOR GLENMORA AND OBERLIN

BASIN: GLENMORA, LA

RAIN GAGE LOCATION	TOTAL AREA	ZONE 1	ZONE 2	ZONE 3
ALEXANDRIA (R)	.03	.02	.04	
LEASVILLE (R)	.25	.02	.38	
WINNFIELD (R)	.01	.00	.02	
ELIZABETH	.03	.08	.01	
HINESTON	.54	.77	.39	
HODGES	.10	.01	.15	
KINDER	.00	.00	.00	
MITTIE	.00	.00	.00	
OAKDALE	.01	.03	.00	
OBERLIN TOWER	.00	.00	.00	
SUGARTOWN	.01	.01	.01	
WOODWORTH	.02	.06	.00	

BASIN: OBERLIN, LA

RAIN GAGE LOCATION	TOTAL AREA	ZONE 1	ZONE 2	* ZONE 3
ALEXANDRIA (R)	.02	.00	.00	.00
LEASVILLE (R)	.16	.00	.00	.00
WINNFIELD (R)	.01	.00	.00	.00
ELIZABETH	.12	.10	.36	.26
HINESTON	.34	.00	.08	.06
HODGES	.06	.00	.00	.00
KINDER	.00	.01	.00	.00
MITTIE	.04	.19	.03	.09
OAKDALE	.16	.32	.46	.40
OBERLIN TOWER	.05	.36	.00	.14
SUGARTOWN	.01	.02	.00	.01
WOODWORTH	.03	.00	.07	.04

*ZONE 3 IS OBERLIN LOCAL AREA (ZONES 1 + 2)

variables and the radiative and aerodynamic properties of the surface. When the surface is wet and imposes no restriction upon the flow of water vapor, the potential value is reached." The principal elements of PE that are observed are temperature, pressure, humidity, wind, solar radiation, and precipitation. The first four of these elements are qualities of the atmosphere, but the last two relate rather to the earth's surface, one constituting the source of soil-temperature and the other source of soil-moisture. For some areas, pan evaporation data may also be available in evaluating PE.

The number of formulas for computation of PE appearing in the literature over the past two decades allows one a wide range of choices. The methods of computation vary from those based on simple relationships using one or more climatic factors to complex equations based on the physics of the evaporation process. A recent study by McGuinness and Bordine (28) utilizing lysimeter-derived PE values showed that six methods of the 14 common methods they tested gave satisfactory daily and monthly results over the entire year when compared with similar lysimeter values. Many investigators have assumed that for practical purposes, PE can be considered equal to free water (lake) evaporation. Theoretically, this assumption is not correct since the albedo of meadows and forest is 10-20%, crops 15-25%, and soils 10-45% [source (26)]. This difference in albedo would indicate that free water evaporation should be somewhat greater than PE. However, since the error associated with the computed free-water evaporation is only 10-15%, it is doubtful that use of a coefficient to reduce free-water evaporation to PE is justified.

The hydrologic model requires that PE be available for each day of the run period. The computational procedure selected is that used by the Lower Mississippi River Forecast Center (LMRFC) located in Slidell, Louisiana. Briefly, it is a modified form of Lamoreaux's (29) equation:

$$PE = E_L = \Big[e^{(T_a-212)\,(0.1024-0.01066 \mathrm{Ln} R)} - 0.0001 + 0.0105(E_s-E_a)^{0.88}(0.37+0.0041U_p)\Big] \cdot \Big[0.015 + (T_a+398.36)^{-2}\,(6.8554\cdot10^{10})e^{-7.4826/T_a+398.36)}\Big]^{-1} \quad (4.4)$$

where

E_L = daily lake evaporation losses (inches/day)

e = Naperian base

T_a = air temperature (F)

R = solar radiation in Langleys/day

E_s = saturation water vapor pressure at T_a

E_a = atmospheric water vapor pressure at T_a

U_p = wind movement six inches above Class A pan (miles/day)

The formula used to reduce wind speeds to pan height has the form:

$$U_p = C4\ (ZIM\cdot U1-C1)^{BETA} + C2 \quad (4.5)$$

where U1 is the observed upper level wind in miles per day and U_p is the wind at the evaporation pan level. ZIM is the coefficient for converting the wind units to miles per day if recorded in other units; otherwise it has the value 1.0. C1 and C2 are corrections to the upper level wind and the pan wind, respectively, and have been usually taken as zero. C4 and BETA are defined,

$$C4 = 1.9577Z_a^{-0.6972} \tag{4.6}$$

$$BETA = 0.9055Z_a^{0.07262} \tag{4.7}$$

where Z_a is the height (feet) above ground of the anemometer used to measure upper level wind. The constants were derived from Lake Hafner evaporation study data and have sometimes been adjusted on the basis of data for the locality under consideration.

Since there are only about 40 solar radiation stations in the United States, it is usually necessary to estimate solar radiation from percent sunshine, where the percent sunshine = (1.0 - tenths of sky cover)·(100). The computer program will accept solar radiation either in Langleys or as tenths of sky cover, making the necessary conversion internally from percent sunshine to solar radiation. Other data required by the program are mean air temperature, mean dew point, and average wind to tenths in miles per day. When the mean dew point temperature is not available, the quantity is computed from four six-hourly dew point temperatures. PE is computed to thousandths of an inch.

Synoptic meteorological data were obtained from NCC for a number of Weather Service first order stations in the southeastern United States. The required meteorological variables were extracted for the first order station closest to the watershed in question, and basin PE computed for the necessary period of record. PE stations and basin assignments are as follows:

COMPUTED PE	BASIN
Jackson, MS	Collins, MS
Jackson, MS	Laurel, MS
Jackson, MS	Edinburg, MS
Lake Charles, LA	Glenmora, LA
Lake Charles, LA	Oberlin, LA
Memphis, TN	Fayetteville, TN
Memphis, TN	Imboden, AK
Springfield, MO	Patterson, MO

These data were then file organized for input to the hydrologic model.

Streamflow

Mean daily discharge records on magnetic tape were obtained from USGS for the eight test watersheds and file organized for input to the hydrologic model. Such data, obviously must be output from the simulation model in order to verify model performance. However, the author wishes to stress this point: model performance evaluation is normally based upon the interpretation of mean daily flow hydrographs only and the resulting statistics, with emphasis placed on the model's capability to match storm generated rises. However, when one is dealing with so few major storms, as is the case during a typical five to ten-year simulation period, with cresting times two to five days, one must question the use of only mean daily flows to draw conclusions. Granted, the use of mean daily flows to achieve a general fit (calibration) of the model to a catchment should be quite satisfactory. However, in view of the fact that the use of mean daily flow figures for error analysis can be justified only on the basis of having a very large number of events with peaks randomly distributed diurnally, this author feels that for research purposes one must also verify against observed instantaneous flows.

The USGS does not maintain instantaneous discharge records in automatic data processing form (cards or magnetic tape). Consequenly, a manual search of precipitation and stage records was undertaken to select storms useful to the research. For the eight test basins rises were so identified and the necessary tabulation of "gage height primary computation" or gage strip charts were ordered from the USGS. Rating curves were then utilized to convert stage to six-hourly instantaneous flow. The time frame for each storm begins with the initial rise in stage and ends when the stream has receded back to or approaches the initial stage. These flow data for significant rises were card coded and a computer program written to organize the data into files unique to each watershed. At this point, both continuous mean daily flow and selected storm instantaneous flow were available on magnetic tape for use by the hydrologic model.

Sources of Error

Hydrologic records, especially those spanning a long term of years, should not be accepted at face value and assumed to satisfy the purposes of a particular study in every respect. Both systematic and random errors must be expected. Some of these may compensate over a period of time; others may not. Also, the records of certain variables involve inherent limitations that may influence the strength of the conclusions derived. Inadequacy of sampling can be a problem. For example, there is ample evidence (34)(35)(36) that instantaneous rates of precipitation at a given station vary considerably from moment to moment. At a particular station, this variability probably compensates to some degree over the term of a single storm, and more so over a season or year. Similarly, among the stations of a network, substantial compensation occurs within the geographic reach of a particular storm or over any extensive area. Nonetheless, even when spaced more closely than is ordinary, a network of precipitation stations takes only a woefully small sample of the water precipitated. In contrast, a stream-gaging station measures the integrated volume of water running off from the drainage area. Thus, the conventional record of streamflow is limited inherently not by inadequacy of sampling, but by accuracy of techniques for measurement.

Since the eight test basins used for this investigation all fall in southern climates, snow measuring is not a problem. However, the point measurement of rainfall is often in error. The true precipitation occurring in the vicinity of the gage may be considerably different from the catch. Improper exposure of the gage or strong winds may diminish the precipitation catch in comparison with actual precipitation. At substations, hours may elapse before the precipitation catch in a light storm is measured on the read once-daily schedule. During that interval an appreciable portion of the catch may be lost due to evaporation. First order and recording stations have shown a greater frequency of days with rainfall greater than 0.01 inch than stations that measure only once daily. A change in location of a station may divide a precipitation record into parts that are not consistent one with another. All things considered, the hydrologic modeler should at least consider the possibility of significantly more rainfall occurring over a watershed than observed when convective-type storms are predominant.

The accuracy of evapotranspiration data required by hydrologic models is unknown. Accurate measurements of ET from crops or from native vegetation is difficult, complex, and costly, and therefore could not be justified for modeling purposes. Most empirical formulas, such as used in this study, require data for which it is difficult to assess an accuracy (duration of sunshine, air temperature, air humidity, and wind speed). For sure, no single climatic index will universally predict ET (37).

Since early 1965, the Geological Survey has been converting its strip-chart recorders to digital recorders producing punched pates that can be processed by machine, thus reducing the chance of human error. Gage heights are punched at 15-minute intervals. Records of stream discharge generally are derived from a "rating curve" which, for each particular site, relates the discharge to stage. Discharge is verified periodically by measurements, usually by current meter, over a range of stage as wide as can be sampled practically. At each measuring station the relationship of discharge to stage depends upon a "control," which is an effect of channel configuration either at a particular cross-section or in a reach of some finite length. Ideally, the control remains at the same cross-section or reach over a wide range of stages, and the stage-discharge relation does not change with the passage of time. All eight river gages appear to have reasonably stable control, and surveys do not indicate channels near the gaging site where flow might by-pass the gage during flood. Discussions with Geological Survey personnel indicate that published streamflow data for the eight headwater basins, but with few exceptions, are highly accurate (90-95 percent).

CHAPTER V

THE SIMULATION MODEL

Introduction and Model Description

There appear to be almost as many "classifications" of simulation models as there are models. One may perhaps view hydrologic models as either stochastic or deterministic, with each of these further broken down as conceptual or empirical. Stochastic models involve the use of multivariate regression analysis to develop predictions of runoff as a function of a limited number of observable variables, such as storm duration, storm intensity, time of the year, and initial moisture conditions. The most advanced hydrologic models (for example, the Stanford Watershed and Sacramento Models) may be considered as conceptual, continuous, parametric, deterministic models. These models perform a water balance--there is complete soil moisture accounting--through interactive mathematics, and were the only two soil moisture accountings seriously considered by this author as research tools. Stochastic models were rejected for a number of reasons: the cause and effect relationships among conditions and processes in a watershed are obscured in the stochastic model, but are used explicitly in the design of a parametric model; in order to take into account all practical variations in watershed conditions, a prohibitive amount of data is required for thorough statistical analysis; and finally, the stochastic model does not lend itself to distributed (zonal or sub-basin) rainfall input which this author feels is frequently necessary for accurate simulation under all storm conditions.

The Stanford and Sacramento Models represent a conceptual analysis of the hydrologic process. The significant conceptual differences are as follows:

1. The "impervious" watershed area is variable in the Sacramento Model and constant in the Stanford Model.

2. The Stanford Model technique for defining areal variablilty (of both runoff and ET) is not used in Sacramento.

3. The Sacramento Model conceives of "tension water" and "free water" as being in the same place and the mathematics are based on this concept.

4. The Sacramento Model includes a mathematical percolation function (formula) which permits constant throughput under saturated conditions.

5. The drainage and percolation computational loop is volume-dependent in the Sacramento Model but time-dependent in Stanford.

This author has calibrated both models for numerous basins in the southwestern and southeastern United States, and is of the opinion that the Sacramento Model is generally preferable for these reasons: conceptually the model is more comprehendable, all parameters are physically realistic, there are fewer parameters to deal with, and most of the major parameters that govern simulation performance can be derived initially from observed hydrographs. Based on studies generated by the World Meteorological Organization (38) and unpublished model comparisons by Sittner (23), one may also conclude that there is evidence that, aside from personal preferences, the Sacramento Model performance is superior to other hydrologic models.

It should be stressed that the model package utilized by this author in researching distributed mode simulation differs significantly from the published Sacramento Model system. In establishing the distributed watershed model, only the soil moisture accounting system of the Sacramento Model was retained. The Sacramento soil moisture accounting procedure was used for each zone or sub-area, but the mechanics of synthesizing or "building" the catchment outflow hydrograph (turning the soil moisture accounting generated runoff depths into a recognizable hydrograph) is substantially changed. The basic Sacramento soil moisture model is the lumped parameter, lumped input type. The originators, while fully cognizant of the spatial variability of rainfall and physical characteristics (hence parameters) within a catchment, did not feel that any existing method of modeling this variation, that they could devise at that time, was adequate or realistic. They therefore opted to design their model as a lumped input-lumped parameter type, and with only minor changes in the basic model used in this study for catchment <u>total area simulation</u>. Additional changes made to the Sacramento Model are: breakdown of precipitation data inputs from 24 hour into six hourly mean inputs (to better model the temporal distribution of rain in calibration mode), and the routing of all five components of flow through a time-delay histogram, rather than applying only direct, surface, and interflow runoff to a unit hydrograph. The basic Sacramento Model computer program used to compare multi-zone model performance was provided by Dr. Erik Anderson, of the National Weather Service's Hydrologic Research Lab.

All flow in any river is originally derived from precipitation. The water, however, falls in different parts of the basin and reach the channel by a great number of routes. The travel may be above or below ground and may require months, years, or no time at all. Consequently, a detailed effort to include all flow components could yield a nearly unlimited number.

The model used herein recognizes and generates five components of flow:

1. Direct runoff, resulting from precipitation input being applied to the fixed and variable impervious areas of the watershed.

2. Surface runoff. When precipitation is supplied at a rate faster than it can enter the upper zone, the excess appears as surface runoff.

3. Interflow, lateral drainage from upper zone free water.

4. Supplementary base flow, rapid lateral drainage from lower zone supplementary free water.

5. Primary base flow, slower (long term) lateral drainage from lower zone primary free water.

Figure 11 presents a conceptual overview of the Sacramento Model. Figure 12 is a more detailed picture of the soil moisture accounting procedure and hydrologic components. Parameters noted in the figure will be defined and discussed in later paragraphs. Much of the following soil moisture model descriptive material was taken directly from National Weather Service internal publications authored by Hydrologic Research Lab. personnel.

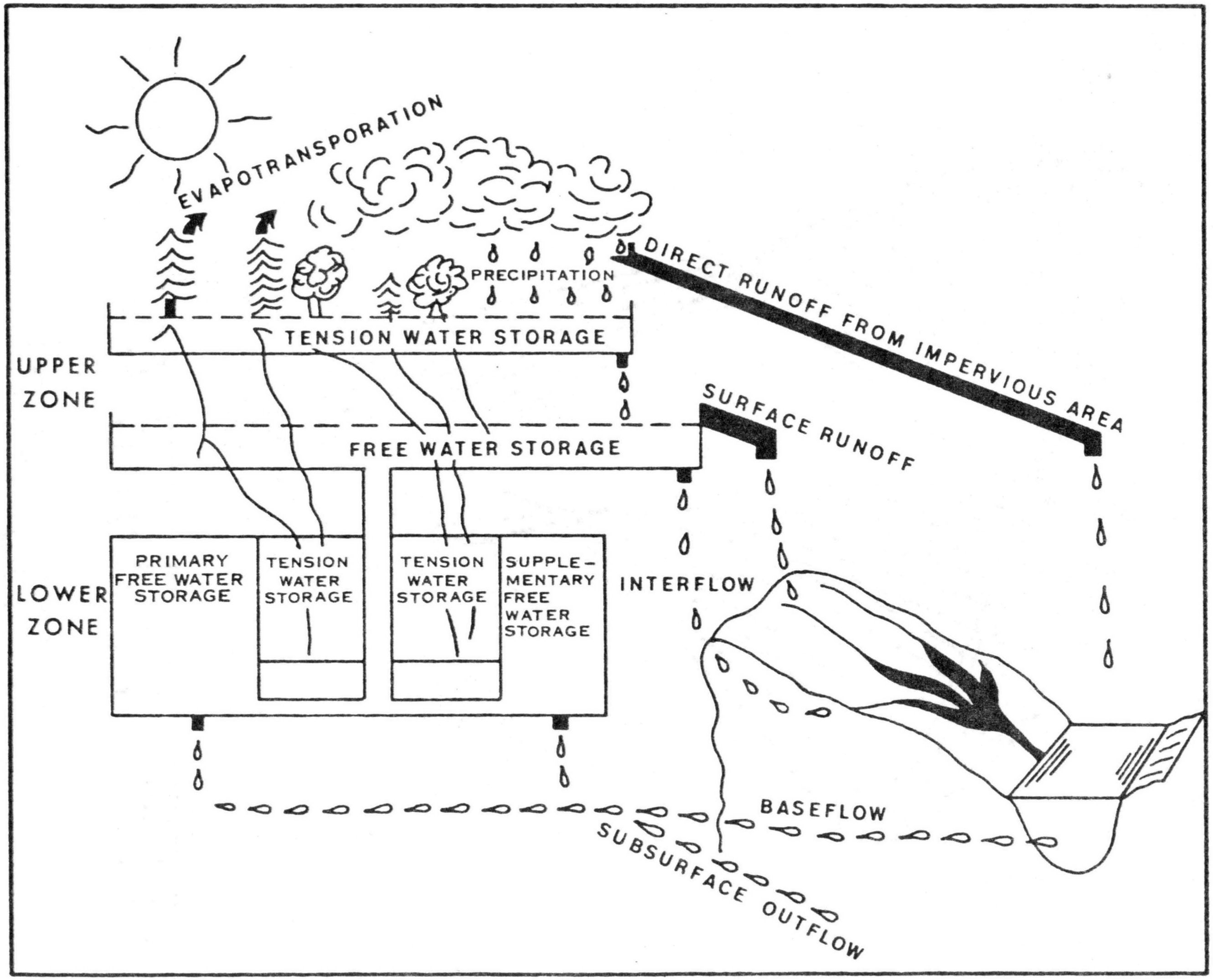


Figure 11. Overview of the Sacramento Model Source: (12), P. 12

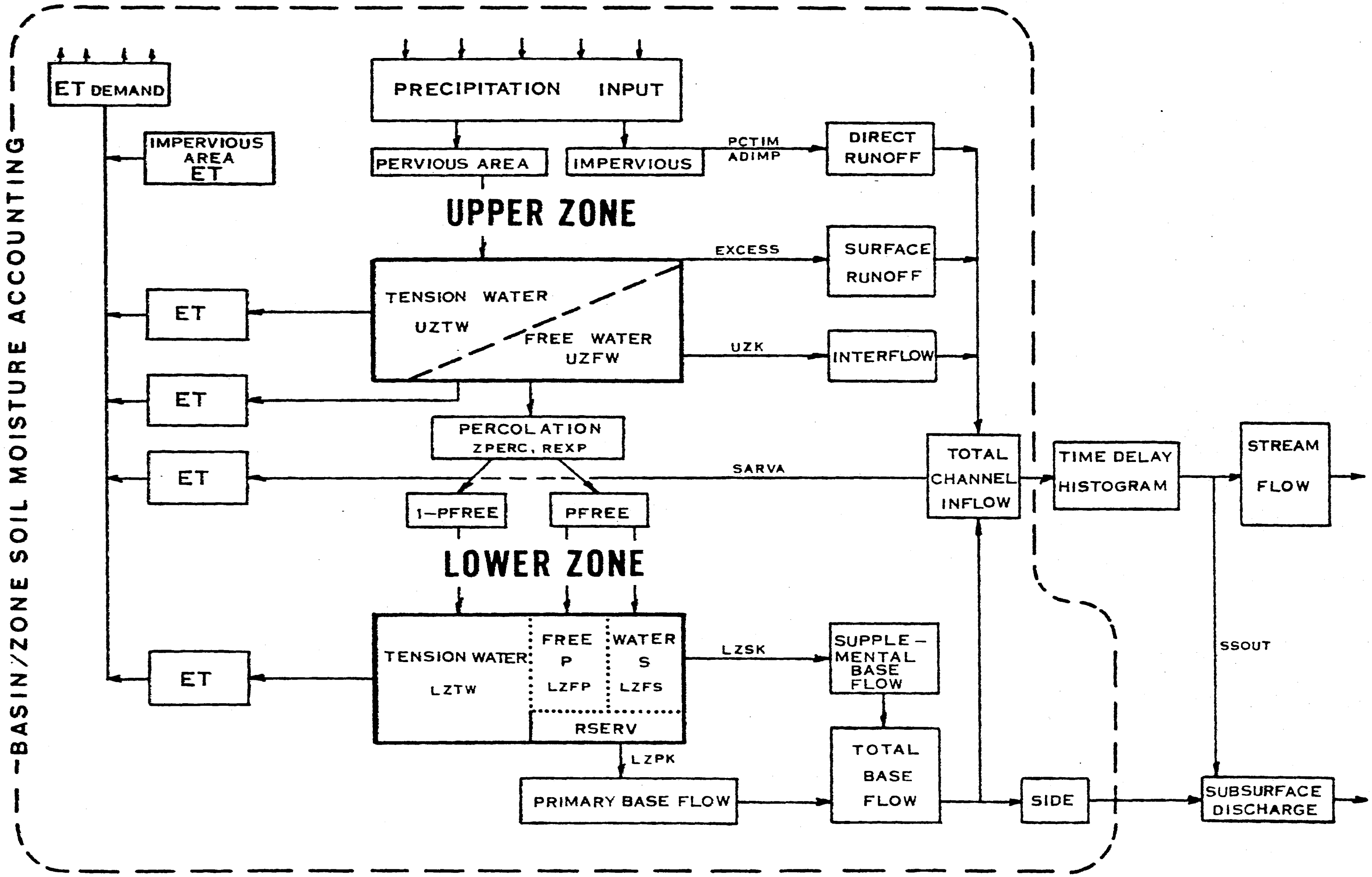


Figure 12. Components of the Hydrologic Model after Burnash (12)

Moisture Storage - Upper and Lower Zone

The soil moisture model structure is basically defined by an upper zone soil mantle and a lower zone aquifer. Each zone is conceptualized as storing "tension" and "free" water. Tension water is that which is closely bound to the soil particles, in contrast to the water that is free for drainage, either vertically or horizontally. In the upper zone, tension water requirements must be met before water is transferred to upper zone free water storage. The provision that tension water requirements be met before substantial drainage begins represents the movement of a wetting front through the soil mantle. In the lower zone a fraction of the incoming water can be transmitted directly to free water storage even if the lower zone tension storage is not full. The capacity to "short circuit" tension water requirements in the lower zone aids the simulation of catchments where significant lower zone drainage is evident, even though area-side, lower zone tension water requirements have not been fulfilled.

Free water can move vertically through percolation, horizontally as interflow, be depleted by ET, or replenish tension water requirements. Tension water storages can be depleted only by the ET process. In summary, the soil moisture accounting expresses the basin as a set of storages of determinable capacities which hold water temporarily and which gradually recede as their contents are diminshed by vertical percolation, evapotranspiration and/or lateral drainage.

Impervious Areas

A fraction of the precipitation falling on the catchment is assumed to be deposited on impervious area directly connected to or adjacent to the channel system. This fraction contributes directly to channel flow, does not enter the soil matrix, and may be considered as a minimum percentage of the basin that exhibits impervious area runoff. However, the model also visualizes a maximum percentage impervious area that may be specified on the theory that as soil moisture storages become satisfied, an increasing amount of pervious area begins to behave as impervious area. An algorithm evaluates the current state of the soil moisture storage system and adjusts the total percentage accordingly.

Percolation

Movement of water from the upper to the lower zone is controlled by a percolation algorithm which relates the contents and capacities of upper and lower zone storages as well as drainage parameters for the respective free water storages. This process is modeled by a quasi-linear, open form computation. The formula controls the movement of water in all portions of the soil profile, both above and below the percolation interface, and is itself controlled by the current state of the soil storage system.

Evapotranspiration

In most rural catchments, ET is the dominant hydrologic process. The model soil moisture accounting system of the model applies ET loss, directly or indirectly from various storages and the channel. The amount of withdrawal is accomplished by a hierarchy of priorities and is limited by the availability of moisture as well as by the computed demand. In other words, the catchment "potential" is a product of meteorological computed PE (discussed in Chapter IV) and a multiplier (monthly adjustment factor to be discussed later) which is a function of the calendar date, and which reflects the state of catchment vegetation on that date.

Calibration Procedures and Parameter Definitions

A difficult problem which always accompanies the use of an advanced model is that of calibration, or "parameter optimization." The determination of the optimal values of ten to twenty interrelated parameters is a formidable task. In working with this model, only manual optimization techniques were employed. The term, manual, refers here to a procedure in which subjective adjustments to various parameters are made on the basis of specific characteristics of the output of previous computer runs. Automatic techniques are those in which the computer adjusts parameters in a semi-random manner, based on changes in the value of a single numerical error function. For example, the "Pattern Search" technique (39). Existing automatic parameter adjustment techniques will not handle a distributed input-distributed parameter model, and even when utilized for "total catchment area simulation," such computer routines have inherent disadvantages. Some of these are complete dependency on one error function, failure to attain an optimal solution due to non-convexity of the response surface in the vicinity of the starting point, and failure to recognize the effect of perturbing a group of parameters simultaneously. At its worst, such a procedure can degenerate into pure curve fitting and produce a set of parameters which fit the calibration data reasonably well, but which are hydrologically unrealistic.

The manual optimization employed to calibrate the simulation model to the eight test basins is best described as "trial and error." After initial parameter values have been selected, either through derivation from historical hydrograph records or by "educated guess," parameters are adjusted in subsequent simulation runs, and error statistics kept to gage the degree of simulation improvement. The error statistics, coupled with a visual inspection of the simulated versus observed hydrographs, indicate the type and degree of parameter changes desired for the next simulation run. This calibration approach requires a knowledge of parameter sensitivity, and some skill to achieve optimum fit. It should be emphasized that it is not always possible to fit a hydrologic model to all basins with great simulation accuracy. Inadequacies in the data base are perhaps the most common cause of failure, though one can never completely rule out the possibility of an inability on the part of the model itself to handle the basin hydrology. It is hoped that the distributed input-distributed parameter model approach researched herein might provide some relief from the failure predicament in model fitting.

Before discussing the individual parameters in the simulation model, it should be made clear the difference between parameters and variables. A parameter is an index to some physical quantity in the watershed hydrologic cycle. The value of a parameter does not change during simulation. It is given a value by the hydrologist ("model fitter") for use in the model, and the parameter value is unique to the basin. A variable is used to represent physical quantities, and the value changes throughout the simulation period. For example, if the parameter lower zone tension water maximum (LZTWM) has a value of six inches, denoting as an index the possibility that the catchment will store physically up to six inches of water in the groundwater aquifer, then the variable lower zone tension water contents (LZTWC) represents the actual depth of water in LZTWM at any given time. The hydrologist selects the initial value of the variable, for the first day of simulation. But from that point on, the model dictates variable values. Finally, a third classification of numbers used by the model may be termed coefficients or "constants." For example, mean basin precipitation adjustment (PX-ADJ), or the 12 monthly PE adjustment factors. Figure 13 is an illustrative hydrograph showing the components of flow and the positioning of the major parameters where parameter influence is most dominant. These and all other parameters in the simulation model are discussed next.

Upper Zone Parameter UZTWM

Upper zone tension water maximum is that depth of water (inches) which must be filled over non-impervious areas before any water becomes available for free water storage. The parameter can be approximated from historical hydrograph analysis: following a dry period when ET has depleted the upper soil moisture, the capacity of the upper zone tension water may be approximated by determining, for an initial storm, the amount of rainfall occurring over the basin before surface runoff commences. The variable UZTWC represents UZTWM contents of any given time. Its initial value for starting the model during a dry period should be zero. A normal range of values for UZTWM is two to seven inches.

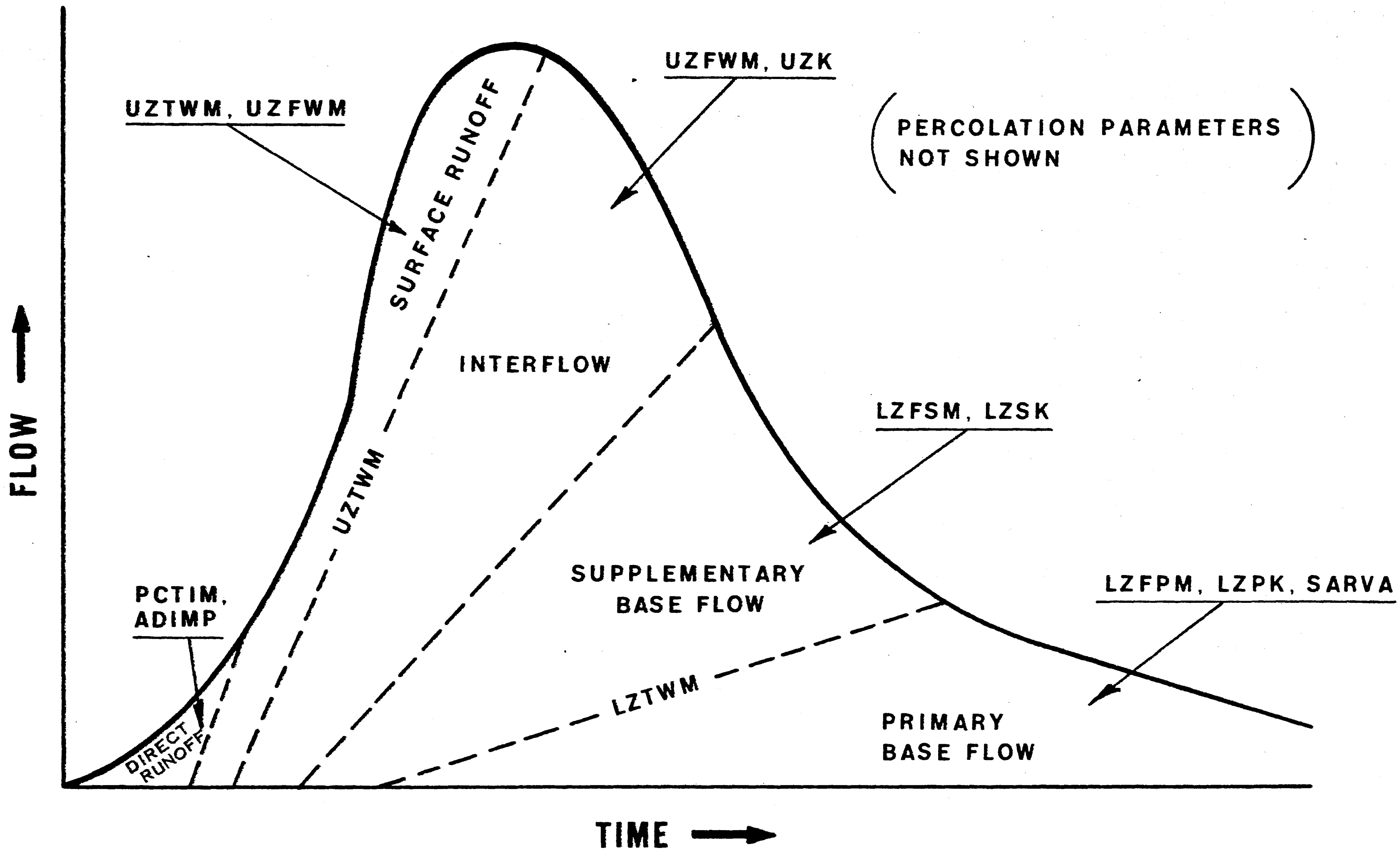


Figure 13. Illustrative Hydrograph of Model Flow Components and Selected Parameters

Upper Zone Parameter UZFWM

Upper zone free water maximum represents the depth (inches) of water which must be filled over the non-impervious fraction of the basin in excess of UZTWM in order to maintain a wetting front at maximum potential. This volume provides the head function in the percolation equation and also establishes that volume of water which is subject to interflow drainage. The contents at any given time is given by the variable UZFWC. The parameter is derived by trial and error, and has a normal range of values 0.5 to 4.0 inches. One inch appears to be a reasonable starting guess for most basins for simulation commencing during a dry period, with UZFWC given a value of zero.

Upper Zone Recession Parameter UZK

UZK is the upper zone lateral drainage rate, and is defined as a ratio of daily withdrawal to available contents. In other words, UZK is the fraction of UZFWC which is drained in one day out of the volume UZFWM. It is simply a depletion constant which may be determined initially from the formula $(1 - UZK)^N = 0.10$, where N is the average number of days over which interflow is observed to occur. A normal range of values is 0.15 to 1.0.

Impervious Area Parameter PCTIM

PCTIM for "percent impervious" is that fraction of the watershed considered impervious and contiguous with stream channels. This is the permanently impervious area, a minimum value. A small rise on the hydrograph during a period of extended dry weather, caused by a brief shower that cannot fill UZIWM, is an excellent indicator of the value of PCTIM. The derivation procedure is to, for that small rise, separate out base flow, and compute the remaining runoff depth in terms of inches of direct runoff over the basin. Then runoff depth divided by rainfall depth equals PCTIM. There is no established range of PCTIM values.

Additional Impervious Area Parameter ADIMP

ADIMP is that fraction of the basin which becomes impervious as all tension water (upper and lower zone) requirements are met. ADIMC variable represents the contents of ADIMP at any given time. ADIMP may be derived by selecting a small rise from light rain following extensive wetting of the soil mantle. Again, as discussed for the parameter PCTIM, base flow is separated out from the small rise, and the value of ADIMP computed. However, experience has dictated that it is satisfactory to set ADIMP = 0 for the initial simulation run, increasing its value in subsequent runs as proves necessary. There is no established range of values for ADIMP. The value of ADIMC for the first day of simulation is best computed by the formula ADIMC = UZTWC + LZTWC. It should be emphasized that runoff response from ADIMP is similar to surface runoff, but whereas runoff from ADIMP can be generated immediately once the upper zone is filled, surface runoff generation is also dependent on upper zone free water storage being filled, and rainfall exceeding interflow depletion rate. ADIMP runoff is mainly a function of basin wetness, while surface runoff is mostly a function of rainfall intensity. The simulation model keeps track of ADIMC water separately from other contents, and it is also depleted separately.

Upper Zone Parameter SARVA

SARVA is defined as that fraction of the watershed covered by streams, lakes, and riparian vegetation, under normal circumstances, and serves the model as a withdrawal function. A SARVA value greater than zero removes water from the stream system, but is last on the ET removal scheme, i.e., water is first lost from the basin through upper zone ET, then the lower zone and SARVA. SARVA should always be less than or equal to PCTIM. Detailed maps of the basin may be used to estimate the extent of paved areas which drain directly into the streams in order that the difference between PCTIM and SARVA can be estimated. A normal range of values for SARVA is 40 to 100 percent of PCTIM.

Percolation Parameter ZPERC

The proportional increase in percolation from saturated to dry condition is defined as ZPERC, a parameter determined only through trial and error. The initial estimate of ZPERC can be arrived at by sequentially running one or two months containing significant hydrograph response following a dry period. The ZPERC value so derived should provide a reasonable generation of runoff once the dry period is ended. Since ZPERC has the most influence when soil is dry, its proportional effect upon computed runoff is greatest at the start of the rainy season. There is no established normal range of values for the parameter, but 75 to 150 percent seems common.

Percolation Parameter REXP

REXP is the exponent in the percolation equation, and determines the rate at which percolation demand changes from the dry condition (ZPERC + 1) · PBASE, to the wet condition PBASE, as indicated in Figure 14. PBASE (to be discussed later) is a function of lower zone storage and lower zone depletion rate. Lower zone soil moisture deficiency (DEFR) is computed by the simulation model according to the formula:

$$DEFR = 1 - \frac{LZTWC + LZFPC + LZFSC}{LZTWM + LZFPM + LZFSM}$$

REXP is determined by trial and error, and an initial estimate of this exponent can be made from the same record used to determine ZPERC. It is obvious from Figure 14 that the percolation curve is generated by the parameters PBASE, ZPERC, and REXP, and the interaction of these terms may require a shift in all three parameters when it becomes clear from the simulation that one term must be changed. REXP chiefly governs the shape of the percolation curve, and has a normal range of values 1.0 to 3.0, with 1.0 often proving to be a satisfactory initial guess.

Percolation Parameter PBASE

PBASE is the saturated percolation rate when the lower zone aquifers are full, and has a value established by the relationship PBASE = (LZFSM · LZSK) + (LZFPM · LZPK). PBASE is not a card input quantity, but rather has a value determined internally by the computer program based upon the card input values of the parameters on the right side of the equation. PBASE Units are inches per day. Figure 14 indicates the position of the parameter on the percolation curve.

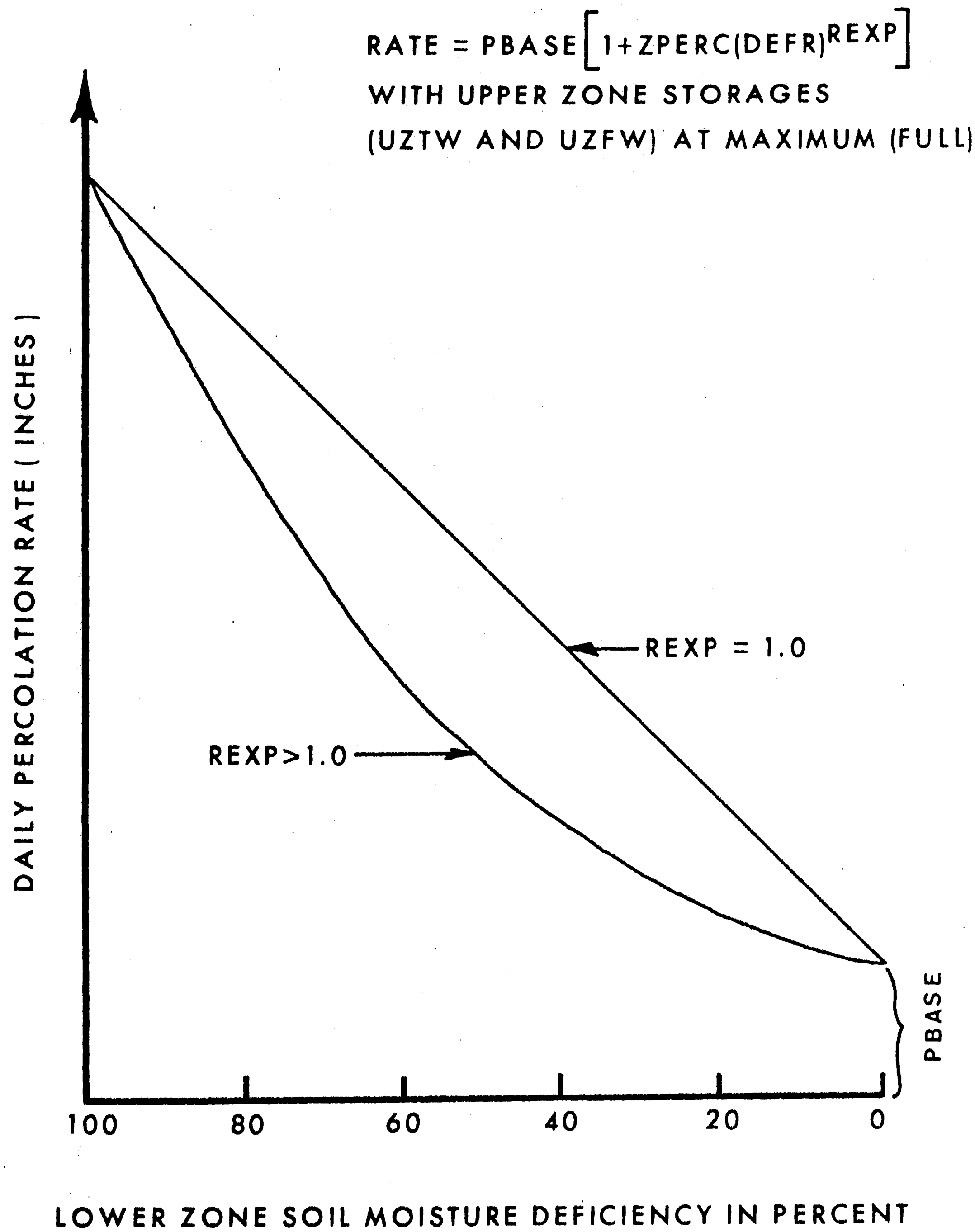


Figure 14. Percolation Presentation

Lower Zone Parameter LZTWM

Lower Zone Tension Water Maximum is the storage capacity of the lower zone. This water volume (depth) is most difficult to determine effectively, since carryover moisture may exist for a period of years. In heavily forested regions of deep rooted conifers, this zone may be as much as 24 inches in magnitude. In areas of deep rooted perennial grasses the depth may be closer to six inches, and in shallow-rooted areas the depth may be as little as three inches. Six inches is perhaps most common, and represents a reasonable starting value in the trial and error calibration of a basin. The contents of LZTWM at any time is given by the variable LZTWC. A reasonable dry weather starting value for the first day of simulation for LZTWC is approximately 30 percent the value of LZTWM.

Lower Zone Parameters LZFSM, LZSK

Lower Zone Free Water Supplemental Maximum is the capacity of the lower zone supplemental free water that has, at any given time, a contents specified by the variable LZFSC. LZSK is the supplemental lateral drainage rate expressed as fraction of the contents per day. LZFSM and LZSK govern the rapid base flow contribution to the hydrograph, and may be derived from observed hydrograph analysis along with two other lower zone parameters, LZFPM and LZPK (to be discussed next). Figure 15 displays ideal recession components as viewed by the simulation model. A semi-log presentation facilitates the separation of the hydrograph recession into component limbs for analysis purposes. The characteristics of the hydrograph recession may be used to obtain

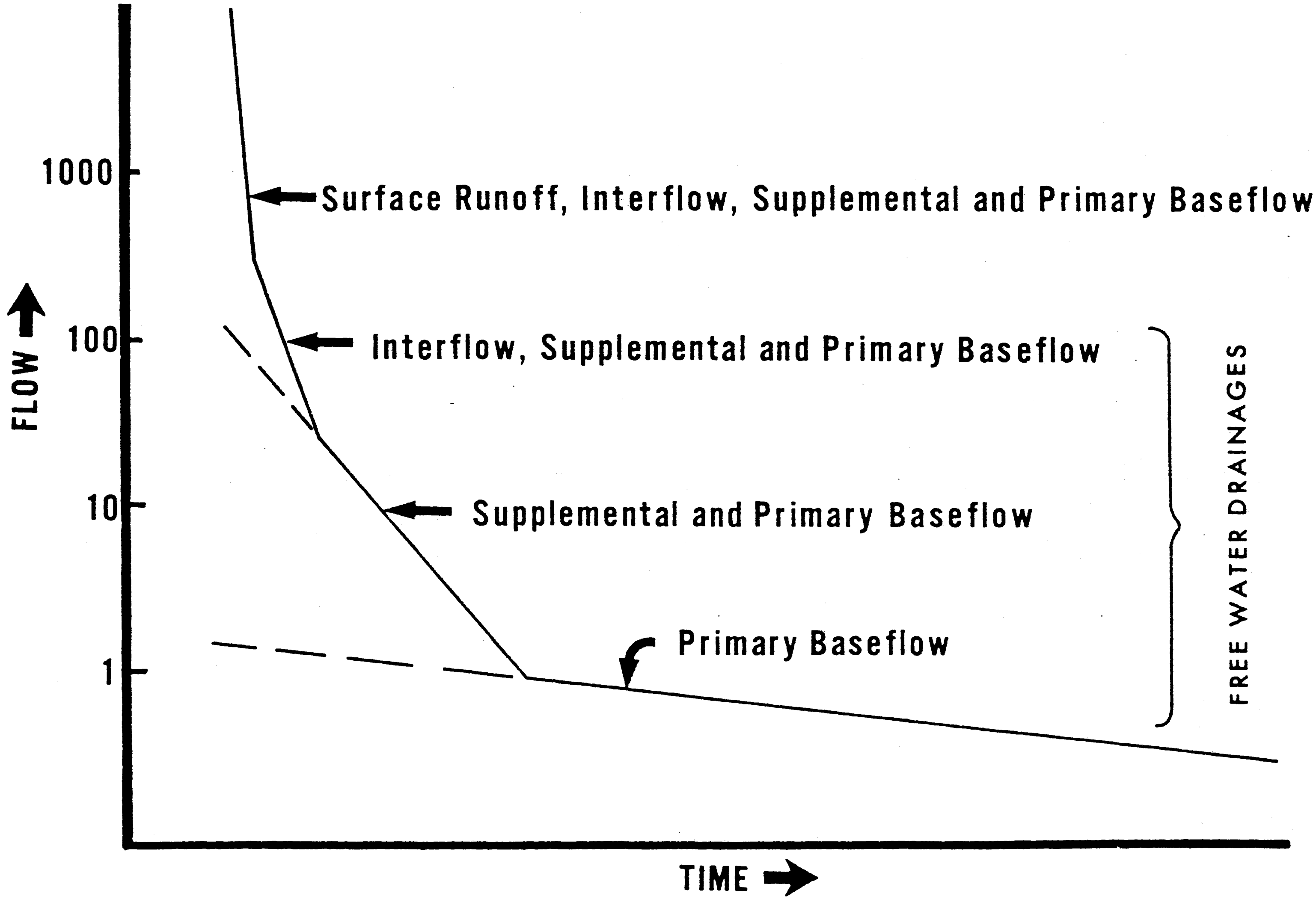


Figure 15. Semilogorithmic Illustrations of Hydrograph Recession Components

initial values for the maximum capacities and depletion coefficients for the lower zone free water storages. If a groundwater recession continues for some time, the recession is characterized by two distinct slopes, with a much flatter recession occurring after a prolonged dry period. The developers of the soil moisture model believe the base flow can be modeled with two slopes representing two separate sources of base flow, supplemental and primary, with separate exponential decay functions. Figure 16 illustrates the mechanics for deriving the base flow zone free water parameters. An ordinate of inches of runoff over the basin is used. A discussion of the LZSK and LZFSM derivation mechanics will be deferred until the primary free water drainage parameters, LZPK and LZFPM are also defined.

Lower Zone Parameters LZFPM, LZPK

Lower Zone Free Water Primary Maximum is the capacity of the lower zone primary free water that has, at any given time, a contents specified by the variable LZFPC. LZPK is the primary lateral drainage rate expressed as fraction of the contents per day. It is the long-term, sustained dry weather base flow that is modeled by the two primary parameters.

To derive LZPK and LZFPM, as illustrated in Figure 16, select from the historical hydrograph record a period when the recession is the flattest (least decay with time), with a minimum of precipitation. Viewing a semi-log hydrograph plot of a storm preceding the dry weather period, through the long term recession, a point QP_o is noted at the supplemental/primary recession slope intersect. Several days later, an arbitrary recession end point QP_t is noted. Then, as shown in Figure

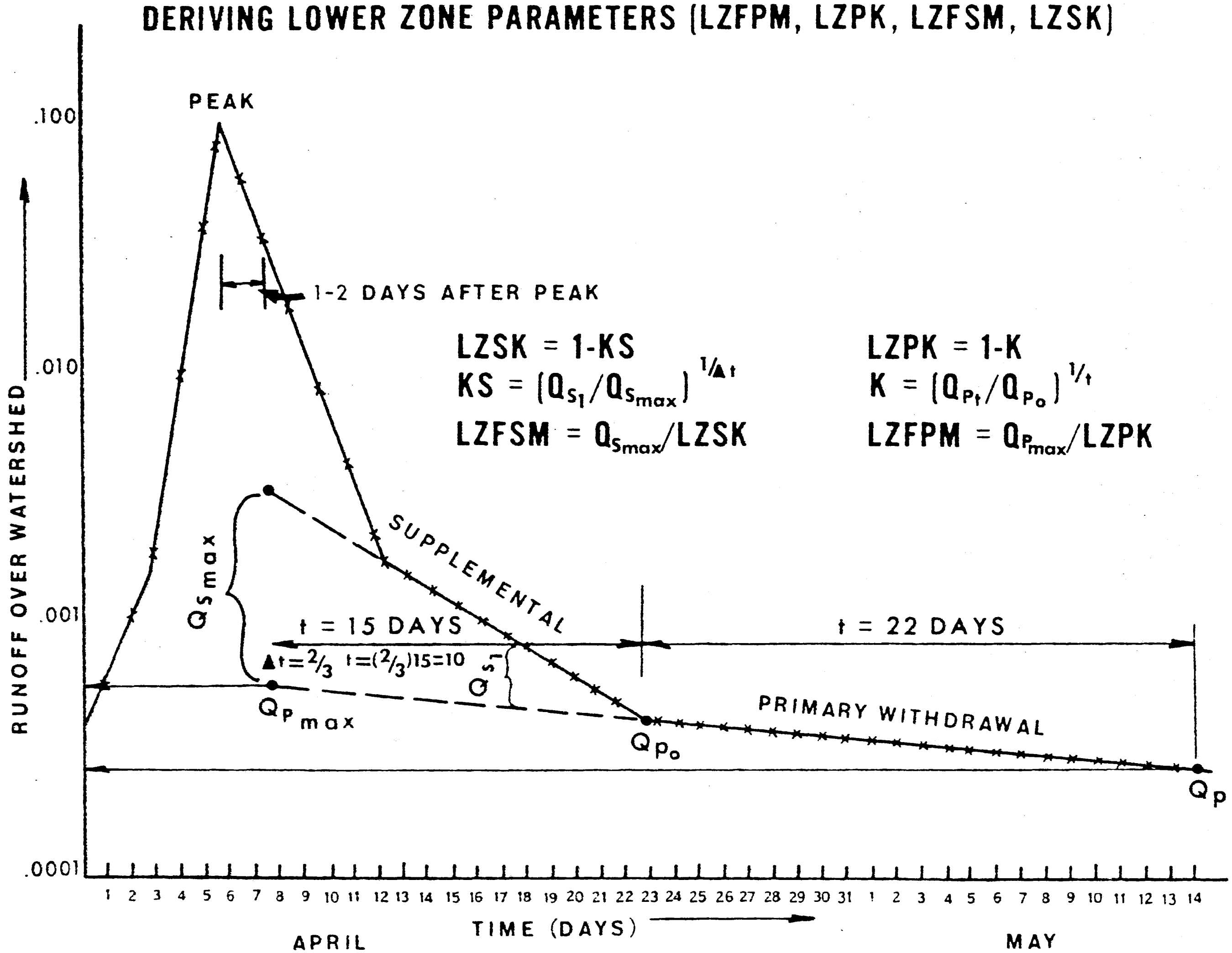


Figure 16. Illustration of Lower Zone Free Water Parameter Derivation

16, the depletion coefficient LZPK is computed. The next step is to extend the primary withdrawal recession to a point just past the storm hydrograph peak, and generally this is a point one or two days past the peak flow, representing a time when primary and supplementary base flow reach the maximum. Obviously, this can vary considerably from basin to basin, so the time past peak flow may range from hours to many days. Similarly, the supplemental recession is extended back under the hydrograph crest. With the point QP_{max} positioned on the primary withdrawal extension, and the maximum supplemental base flow point identified, a QS_{max} quantity is determined, representing the difference between peak primary and peak supplemental flows. Then, as indicated in Figure 16, the parameter LZFPM is computed.

To determine the supplemental withdrawal parameters, one must also determine the value of QS_1, a quantity indicating, rather arbitrarily, a lower zone supplemental versus primary discharge difference at a time two-thirds the time period between the occurrence of QP_{max} and QP_o. Once such quantities are determined analytically, it is a simple matter to compute the decay coefficient LZSK and storage parameter LZSFM.

LZSK values seem to range, for most basins, from 0.01 to 0.09, and LZPK values 0.001 to 0.009. The values determined for LZFSM and LZFPM from hydrograph analysis tend to be minimum values, and often must be adjusted upwards during trial and error calibration. There is no established normal range of values. The contents of these lower zone free water storages, for starting up the simulation model during dry weather, can be zero for LZFSC and 30 percent of LZFPM for the variable LZFPC.

Lower Zone Parameter PFREE

PFREE represents that fraction of the percolated water which is transmitted directly to the lower zone free water storages without prior claim by lower zone tension water deficiencies. The parameter can be set to zero during initial calibration, and increased after all other model parameters are fairly well established and simulation is good. A relative value of PFREE can be determined by investigating small storms following long dry spells that do produce surface runoff. If the hydrograph returns to approximately the same baseflow as before the rise (indicating little or no addition to the lower zone free water storages), then PFREE is of little significance in the watershed and has a small value ranging from 0.0 to 0.2. If there is a significant increase in baseflow following this type of storm, then PFREE can have a value as high as 0.50. The nominal value of the parameter appears to be 0.30.

Lower Zone Parameter RESV

That fraction of the lower zone free water which is unavailable for transpiration is defined as RESV. This parameter has very low sensitivity and generally need not be optimized to achieve effective simulation. A typical range of values is 0.0 to 0.40, averaging on the order of 0.30 for most basins.

Lower Zone Parameter SIDE

SIDE represents that portion of base flow water that is not observed in the stream channel. When soil is saturated, and if percolation takes place at a rate which is greater than the observable baseflow, then the need for additional soil moisture drainage becomes manifest. SIDE is the ratio of the unobserved to the observed baseflow. When the saturated soils do not drain to the surface channel, SIDE allows the correct definition of PBASE, in order that the saturated percolation rate may be achieved. In all area where all drainage from baseflow aquifers reaches surface channels, SIDE has a value of zero. However, in areas subject to extreme subsurface drainage losses, SIDE may be as high as 5.0. In short, SIDE is a non-channel groundwater loss parameter, representing the ratio of non-channel baseflow to channel baseflow.

Channel Parameter SSOUT

The parameter SSOUT is a constant streamflow loss (+) or gain (-) factor. It is the subsurface outflow along the channel which must be provided by the stream before water is available for surface discharge. There is no established range of values for SSOUT, but most watersheds indicate a zero parameter value.

Channel Parameter KS1

KS1 is the channel storage attenuation factor applied to the inflow time-delay histogram. As the routing algorithm is applied to the six-hourly inflow means, storage attenuation must be considered to produce a proper instantaneous outflow hydrograph from the basin outlet gage (see Figure 18). The larger the KS1 factor chosen, the greater the hydrograph attenuation due to channel storage effects. The parameter, then, allows the modeler to vary the shape of the hydrograph. If KS1 is kept constant regardless of the inflow magnitude, the histogram acts as a unit hydrograph. If KS1 is allowed to vary with flow, the linearity restriction of the unit graph is largely overcome.

The algorithm formulated to route time-delay inflow to the basin outlet is basically reservoir routing governed by the relationship

$$\frac{dS}{dT} = I - Q = KS1 \frac{dQ}{dT} \tag{5.1}$$

where S is the reservoir storage, KS1 the reservoir storage constant, and I and Q are the reservoir inflow and outflow, respectively, at time T. It can be shown that the relationship may be manipulated so that, for a routing interval of six hours, the instantaneous outflow at the end of a six-hour period (Q_2) is given by the equation

$$Q_2 = \bar{I}\left(\frac{6}{KS1 + 3}\right) + Q_1\left(\frac{KS1 - 3}{KS1 + 3}\right) \tag{5.2}$$

where $\bar{I}$ is six-hourly mean inflow (a time-delay histogram element), and Q_1 is the instantaneous outflow at the beginning of the six-hour time period. Equation (5.2) was programmed to handle the basin inflow routing task.

Input Data Adjustment Constants

Three constants are available to the modeler for adjusting watershed calibration data. PX-ADJ allows one to apply a correction factor to mean basin precipitation (MBP) or mean zone precipitation (MZP). If PX-ADJ = 1, the average precipitation as computed (Chapter IV) and loaded in the input data files is used. If, for example, PX-ADJ is set equal to 1.2, a 20 percent increase in the average precipitation is performed (for all MBP or MZP) before the simulation model processes the data. This adjustment feature can be handy, as frequently thunderstorm rain gage blow-by causes a catch much lower than should be the case, and PX-ADJ allows the modeler to increase the computed average rainfall and thus better simulate actual conditions.

Similarly, the constant PE-ADJ allows a "blanket" adjustment upward or downward to computed basin or zone daily PE (Chapter IV). Additionally, the meteorological PE may be changed through the use of 12 monthly adjustment factors, each of which applies a correction to meteorological PE on the 16th of each month. An adjustment factor of, say, 0.8 for February and 1.0 for March, causes the daily PE on file to be reduced 20 percent on the 16th of February, and not adjusted on the 16th of March, with daily PE between the two mid-months adjusted according to a linear interpolation algorithm. If all twelve monthly adjustment factors have the value of, say, 0.7, the correction is equivalent to setting PE-ADJ = 0.7. Regardless of how the correction is applied, the net effect is to adjust meteorological (free water PE) to a more realistic watershed PE, called "basin ET demand," as displayed in Figure 17 for the Elk River basin at Fayetteville. The actual basin evapotranspiration taking place during simulation is a function of the basin daily ET demand and available soil moisture.

The model does not apply an ET demand at night, which is consistent with observations (measurements) reported in standard texts. ET demand works from "top-down" in the soil moisture accounting model. For areas covered by surface waters, the evaporation is computed at the potential rate. For the remainder of the basin, actual ET is a function of the ET demand and the water in tension water storage. ET occurs from the upper zone at watershed demand rate multiplied by the

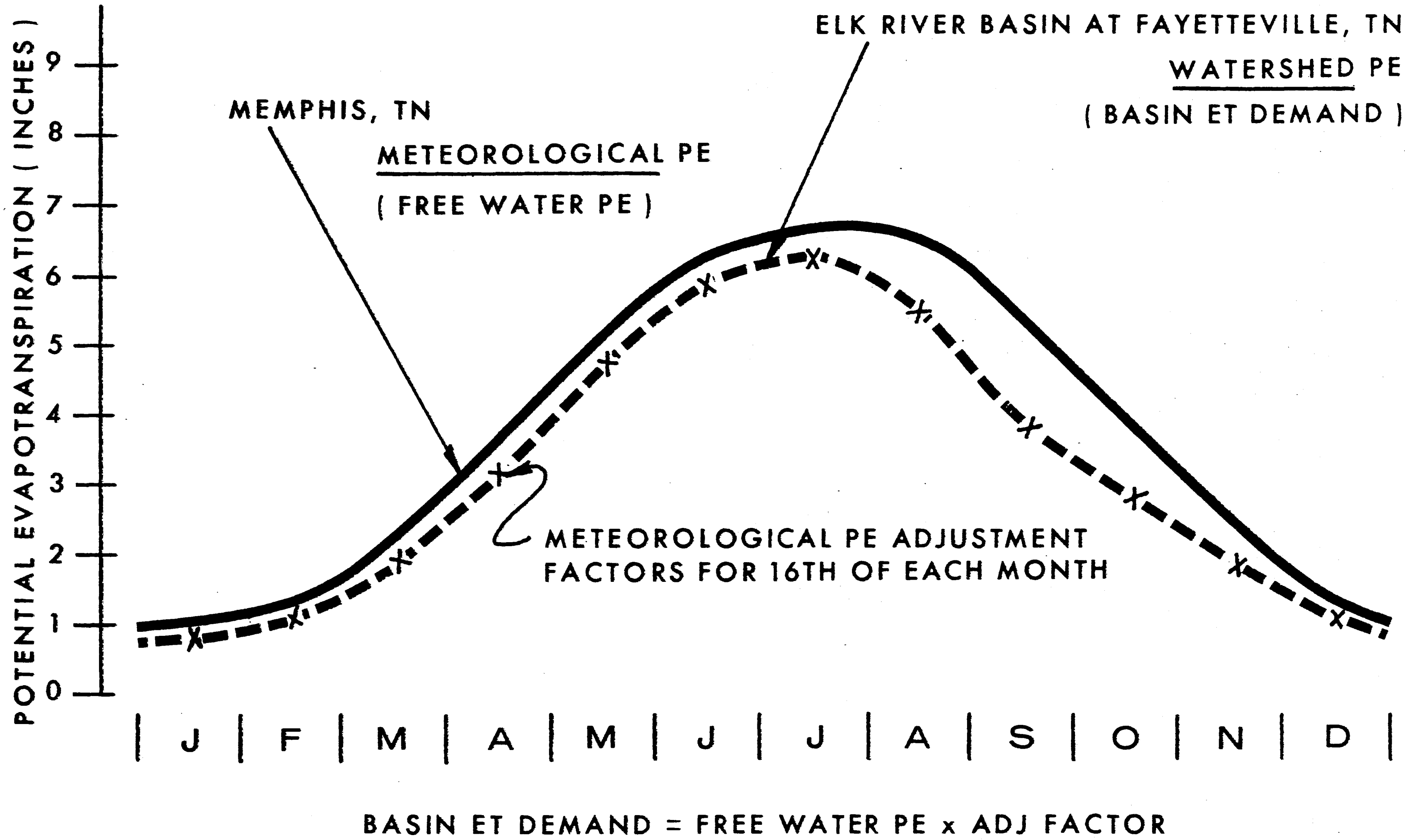


Figure 17. Illustrative Monthly Potential Evapotranspiration and Calibration Adjustments

proportional loading of the upper zone tension water storage. It occurs from the lower zone at a rate equal to

$$\text{(Unsatisfied Watershed Demand)}\cdot\left(\frac{\text{Lower Zone Tension Water Contents}}{\text{Total Tension Water Capacity}}\right)$$

and if the ratio

$$\frac{\text{Free Water Contents}}{\text{Free Water Capacity}} \text{ exceeds the ratio } \frac{\text{Tension Water Contents}}{\text{Tension Water Capacity}},$$

water is transferred from free water to tension water and the relative loadings balanced in order to maintain a consistent soil moisture profile. A fraction of the lower zone free water is not available for such a transfer, as it is considered to be below the root zone. If the basin ET demand, then, cannot be fully satisfied by availability of upper zone tension water, the soil moisture accounting model also pulls water out of the lower zone, as discussed earlier. Finally, if there is still some residual ET demand that cannot be satisfied by either the upper or lower zone, SARVA is utilized to satisfy ET demand.

Model Components

The parameters and concepts discussed in previous paragraphs can perhaps be better understood if they are viewed as model components grouped and summarized as follows [after Burnash (12)]:

Direct Runoff and Evaporation

1. Fraction of impervious basin contiguous with stream channels, PCTIM.

2. The fraction of impervious area which appears as tension water requirements are met, ADIMP. The total of ADIMP and PCTIM may be

considered potential impervious.

3. Fraction of the basin covered by streams, lakes, and riparian vegetation, SARVA.

4. Evapotranspiration demand.

Upper Zone Tension Water

1. Maximum capacity in inches, UZIWM.

2. Contents in inches, UZTWC

Upper Zone Free Water

1. Maximum capacity in inches, UZFWM

2. Contents in inches, UZFWC

3. Lateral drainage rate expressed as a fraction of contents per day, UZK.

Percolation Rate from Upper Zone Free Water into Lower Zone

1. The through-put rate during saturated conditions, PBASE.

2, The proportional increase in percolation from saturated to dry conditions, ZPERC.

3. An exponent determining the rate of change of the percolation rate with changing lower zone water contents, REXP.

4. A complete percolation function governed by the equation

$$\text{RATE} = \text{PBASE}\left[1 + \text{ZPERC}\ (\text{DEFR})^{\text{REXP}}\right] \cdot \frac{\text{UZFWC}}{\text{UZFWM}} \qquad (5.3)$$

Lower Zone Tension Water

1. Maximum capacity in inches, LZTWM.

2. Contents in inches, LZTWC.

Lower Zone Free Water

1. Supplemental free water storage.

a) Maximum capacity in inches, LZFSM.

b) Contents in inches, LZFSC.

c) Lateral drainage rate expressed as fraction of contents per day, LZSK.

2. Primary free water storage.

a) Maximum capacity in inches, LZFPM.

b) Contents in inches, LZFPC.

c) Lateral drainage rate expressed as a fraction of contents per day, LZPK.

3. Direct percolation to lower zone free water, PFREE, the percentage of percolated water which enters the lower free water aquifer directly without a prior claim by lower zone tension water deficiencies.

4. Ground water discharge not observable in the river channel.

a) Ratio of non-channel subsurface outflow to channel baseflow, SIDE.

b) Discharge required by channel underside, SSOUT.

5. Fraction of lower zone free water incapable of resupplying lower zone tension, RESV.

Channel Storage Characteristics to Modify the Flow Obtained from the Channel Response Function

1. KS1, a fixed or variable (with flow) attenuation factor.

A Channel Response Function

1. Time-Delay Histogram.

The Channel Response Function

Channel response functions used for hydograph synthesis take many forms. Certainly the most common method is the unit hydrograph, or unit graph as it is often called. Originally formulated by Sherman (40) in 1932, and discussed in the literature since (41)(42)(43)(44)(45), the unit graph concept is widely applied in hydrologic science and engineering. The three basic propositions of unit graph theory, all of which refer solely to the surface runoff hydrograph, are:

1. For a given drainage basin, the duration of surface runoff is essentially constant for all uniform-intensity storms of the same length, regardless of differences in the total volume of surface runoff.

2. For a given drainage basin, if two uniform-intensity storms of the same length produce different total volumes of surface runoff, then the rates of surface runoff at corresponding times, t, after the beginning of two storms, are in the same proportion to each other as the total volumes of surface runoff.

3. The time distribution of surface runoff from a given storm period is independent of concurrent runoff from anticedent storm periods. In propositions 1 and 2, the phrase "uniform-intensity storm" is to be taken as meaning a storm which produces a reasonably uniform depth of rainfall over the entire drainage basin and in which the rate of rainfall is, within rather broad limits, constant. All of these propositions are empirical. It is not possible to prove them mathematically. In fact, as stated by Johnstone and Cross in "Elements of Applied Hydrology" (out of print), "it is a rather simple matter to demonstrate by rational hydraulic analysis that not a single one of them is mathematically accurate." Fortunately, nature is not aware of this. Regardless, the deficiencies in the unit hydrograph approach may prove troublesome. In particular, the areal distribution of rainfall (and resulting runoff) generated during storm periods for which

the simulation model is run can be considerably different from the storms used in developing the unit graph. Also, the assumed linear relationship between channel storage and discharge can be considerably in error. Both deficiencies can be at least partially overcome through the use of a channel response function of the time-delay histogram form with variable K (or KS1, as storage attenuation factor is termed in this report). The only reason that unit graphs work as well as they do is that in present day practice the unit graph does not represent runoff "generated uniformly over the basin area," but rather runoff generated in some characteristic but non-uniform manner. Sittner (23) feels that Sherman probably also thought in terms of the unit graph defining the movement of water from the point where it fell (or melted) to the channel outflow point rather than to just a portion of that route. He could not be expected to have anticipated that some day someone might want to apply a unit graph to the channel system rather than the entire catchment and account for the prior delay by depletion functions or some other means, as in the case with most conceptual hydrologic models.

Storage and flow times in the channel system are generally large when compared to those in overland flow, and as the size of the catchment increases, the more the channel system dominates the shaping of the basin outflow hydrograph. As pointed out by Sittner (23), the term "histogram" implies that a function is defined by a series of successive ranges of the independent variable, rather than by a continuous curve representing a series of discrete points, as is the case with a unit hydrograph. Thus, if a unit graph is defined by a series of 6-hour mean flows (normalized or not), it is a histogram, and if defined by a series of ordinates representing instantaneous discharge, it is not a histogram. This is so, regardless of whether it describes the time delay for the entire catchment or just the channel system. For the research simulation model described in this report when applied to catchment total area drainage, the channel response function is a unit hydrograph expressed as a histogram, but when applied to sub-areas (zones) to account for rainfall non-uniformity and to maintain sub-area soil moisture accounting, the histogram loses its unit graph identity.

The time-delay histogram, then, is a time versus discharge channel response function that represents the response of the channel to an in-flow with duration equal to some Δ T time increment. And as described in Chapter III in the Isochronal Analysis section, each element of the histogram represents the fraction of the total watershed contributing to channel flow in a given 6-hour travel time. Each element of the histogram is associated with a particular travel time zone of the basin. The inflow hydrograph in the form of 6-hourly mean ordinates of flow generated by the string of all elements is then routed through a linear reservoir at the basin outflow point, using channel parameter KS1, to produce an instantaneous basin outflow hydrograph. Figure 18 illustrates the procedure using the Fayetteville, Tennessee, watershed as an example. The soil moisture accounting portion of the simulation model generates every six hours a runoff depth to the channel. The accounting is performed in computer subroutine called "Land." This runoff depth (the sum of all five runoff components) is then multiplied by drainage area to yield a total runoff volume for the 6-hour period. This volume is then applied to the time-delay histogram, which allocates total run-off to 6-hourly flow values properly lagged. Then, as stated earlier,

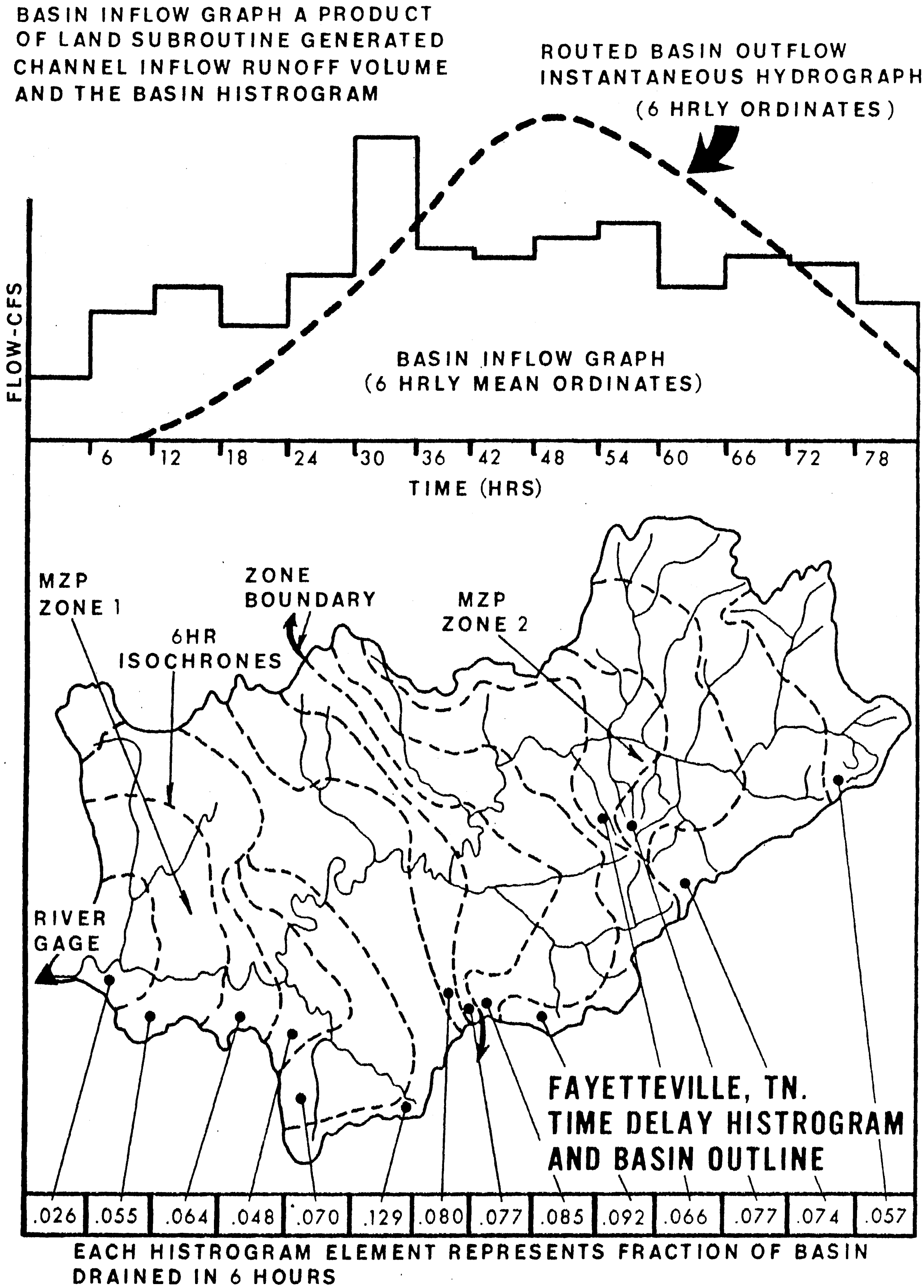


Figure 18. Example of Isochrone, Histogram, and Basin Inflow-Outflow Hydrograph Linkages

the inflow hydrograph is routed to the basin outlet. The procedure is no different if separate mean zone precipitation (MZP) is utilized rather than total area mean basin precipitation (MBP). However, in the former case, the inflow graph may take on quite different shape depend- upon the non-uniformity of rainfall and zone soil moisture antecedent conditions/zone parameter values. In other words, a distributed model (as opposed to the lumped parameter model) will often decide the magnitude and shape of the resulting hydrograph, rather than the hydrograph being a function of total area mean basin storm precipitation only.

A few final words are in order regarding the use of channel parameter KS1, storage attenuation factor, and its relation to the channel response function. Even when employing zones via a distributed hydrologic model, the histogram response to runoff within each zone is linear. A variable KS1 generates a response that is non-linear, and should be used when the basin hydrograph exhibits storage characteristics such that attenuation is not constant with outflow. Basins with flat topography probably do not call for a variable KS1. Some hydrologists have even gone so far as to apply a variable lag to the inflow in order to match observed catchment outflow, though this procedure has little physical justification when applied to conceptual models. Such "engineering hydrology" has not been utilized in fitting the simulation model to the eight research watersheds. It is the sub-area/time-delay histogram approach to synthesizing the hydrograph that clearly distinguishes the distributed model from the basic Sacramento total area catchment model. It is a modeling technique that should allow for better simulation performance over a wider range of hydrologic conditions.

CHAPTER VI

RESEARCH METHODOLOGY AND RESULTS

Introduction

For many years, research and field hydrologists have used a distributed input lash-up to API type rainfall-runoff relationships in computing sub-basin runoff depths. A single watershed study, originally conducted by this author in 1973, attempted to utilize the same approach with a conceptual hydrologic model, seeking to determine the possibility of improving streamflow simulation through the use of zonal precipitation input and then also zonally varied parameters. The data from this research did not yield hard scientific evidence of distributed modeling superiority, but the results were nonetheless intriguing. In comparing the conventional lumped input-lumped parameter (total catchment area) Stanford Model to an altered version using distributed input-distributed parameters, standard statistical measures of simulation accuracy (root mean square error, bias, correlation coefficient, etc.) indicated no significant advantage to be gained by calibrating a multi-zone hydrologic model. However, a close examination of the monthly statistics revealed a definite seasonal relationship. That is, in the winter the distributed model hurt the results. In the spring and early summer it improved them, and mid-summer through fall at least the distributed model did no harm. This is meaningful and encouraging, since the type of situation in which it was thought simulation could be improved was that where spatially variable convective storms generated significant rainfalls, and such storms do prevail during spring and summer. Unfortunately, only mean daily discharge data were available for examination, and there was no measure of the degree of rainfall non-uniformity other than visual inspection of the computed mean zone precipitation. It was concluded that more sophisticated statistics were in order for the type of analyses required. In particular, a statistic that measures the degree of simulation improvement related to the degree of rainfall non-uniformity and checked against instantaneous flow hydrographs, would be most useful. Experience thus gained from the 1973 multi-zone pilot study suggests a research methodology that is applied in this eight basin report, the object being to conduct a more exhaustive simulation investigation with maximum effectiveness.

Simulation Statistics

The principal reason for evaluating distributed simulation model performance over so many basins for so many years was to allow testing against a sufficiently large sample of events so as to assure, with much confidence, that results were meaningful in a statistical sense. Standard statistical significance tests are generally not utilized in hydrologic data analyses of the type made in this report, since the underlying assumptions upon which the tests are based may not be obeyed. The simplest and most practical solution is to test against independent sets of meteorological/hydrological data (46). In view of the fact that the distributed model is tested against eight independent watershed data sets of lengthy record in this study, and has been applied to other watersheds with equal success (20), it is felt that conclusions drawn from the resulting statistical information are sound. A somewhat different approach to model testing that was considered but rejected is the split sample technique. Many research hydrologists will divide a simulation data set into two periods, one period being used for model calibration and the second for model performance testing. It is this author's opinion that split sample testing has limited utility in hydrology, and probably tells more about the data set than about the model. As pointed out by Sittner (23), a two-year test period combined with a six-year calibration period, for example, can be shown mathematically to have a low degree of significance. The conclusion is, therefore, that while test period results should not be ignored, no great weight should be given to them in drawing conclusions.

The assimilation of large volumes of data in a hydrologic model research effort requires that the statistics chosen to judge model capability have clear and fully relevant meaning to the objective. If there is question as to the interpretation of what the statistic measures, the statistic should not be used. With this philosophy in mind, several numerical verification criteria were selected for model error analyses. These error analyses, unless specified otherwise, are based on the differences between the simulated and observed values of either mean daily discharges or monthly volumes, not on ordinates representing instantaneous discharge. The reasoning here is that even small timing errors should affect the error functions based on mean daily values, since the time of occurrence of runoff events is, in general, randomly distributed throughout the day. However, while this reasoning is sound for evaluating, in a comprehensive fashion, the overall performance characteristics of a simulation model, timing and individual storm error must be considered explicitly to expand model evaluation to include the effects of distributed input and distributed parameters. Mean daily flow analyses may not be adequately sensitive to hydrograph changes brought about by simulating in the distributed mode. Based on these considerations, the following statistics are presented as logical measures of the quantitative performance of the simulation model.

1. Simulated mean daily flow (SMDQ) and observed mean daily flow (OMDQ). Values are CFSD. The monthly mean daily flow is the summation of MDQ divided by the number of days in the month. The water years MDQ is the summation of MDQ for all years (simulated or observed) divided by the total number of days in the multiyear period.

2. Bias is defined as SMDQ minus OMDQ. Percent Bias, then, is the bias divided by OMDQ.

3. Maximum error is the absolute value of SMDQ minus OMDQ for any given period of record. Generally, the maximum error occurs during a major rise on the river.

4. Correlation Coefficient (R) is computed from the equation

$$R = \frac{N \cdot \sum_{1}^{N} SMDQ \cdot OMDQ - \sum_{1}^{N} SMDQ \cdot \sum_{1}^{N} OMDQ}{\left[\left(N \cdot \sum_{1}^{N} SMDQ^2 - \sum_{1}^{N} SMDQ \cdot \sum_{1}^{N} SMDQ\right) \cdot \left(N \cdot \sum_{1}^{N} OMDQ^2 - \sum_{1}^{N} OMDQ \cdot \sum_{1}^{N} OMDQ\right)\right]^{\frac{1}{2}}} \quad (6.1)$$

where R measures the linear correlation between the values of SMDQ and OMDQ for the number of cases N. The Correlation Coefficient may take on positive values ranging from zero to unity, representing no correlation or perfect correlation, respectively, about the best fit line.

It is common in streamflow statistical analysis to obtain a good correlation coefficient but yet have a bad bias.

5. Best Fit Line. In many disciplines it is desirable to express one variable in terms of another even though the variables are independent and not necessarily analytical functions of each other. An accepted practice is to perform a least squares linear regression which is designed to minimize the sum of the squares of the deviations of the actual data points from the straight line of best fit. With the least squares analysis completed, the resulting line of regression has the form

$$OMDQ = A \cdot SMDQ + B$$

where A represents the slope of the straight line and B the Y-intercept. The least squares regression effectively constructs a plot (scatter diagram) of the variables SMDQ versus OMDQ, and draws the best straight line fit. A perfect relationship between the variables SMDQ and OMDQ would result in a 45-degree line with A = 1 and B = 0. As the line approaches a 45-degree angle, we are seeing a reasonably unbiased fit at all flow levels, and therefore the statistic implies the same information as would a flow interval table of statistics. The values of A and B are computed from the equations

$$A = \frac{N \cdot \sum_{1}^{N} OMDQ \cdot SMDQ - \sum_{1}^{N} SMDQ \cdot \sum_{1}^{N} OMDQ}{N \cdot \sum_{1}^{N} SMDQ^2 - \sum_{1}^{N} SMDQ \cdot \sum_{1}^{N} SMDQ} \qquad (6.2)$$

and

$$B = \frac{\sum_{1}^{N} OMDQ \cdot \sum_{1}^{N} SMDQ^2 - \sum_{1}^{N} SMDQ \cdot \sum_{1}^{N} SMDQ \cdot OMDQ}{N \cdot \sum_{1}^{N} SMDQ^2 - \sum_{1}^{N} SMDQ \cdot \sum_{1}^{N} SMDQ} \tag{6.3}$$

The Best Fit Line is an excellent statistic for visualizing model performance over the entire range of flows. However, it is meaningful only when one is dealing with a large range of MDQ values, as obviously a dense cluster of SMDQ versus OMDQ for a narrow range of flows does little to assure proper line definition. Consequently, the Best Fit Line is computed only for the total of all water years.

6. The Root Mean Square Error (RMS) in CFSD is often used in model testing as the primary statistic to judge overall simulation accuracy. RMS is defined by the equation

$$RMS = \left[\frac{\sum_{1}^{N} (SMDQ - OMDQ)^2}{N} \right]^{\frac{1}{2}} \tag{6.4}$$

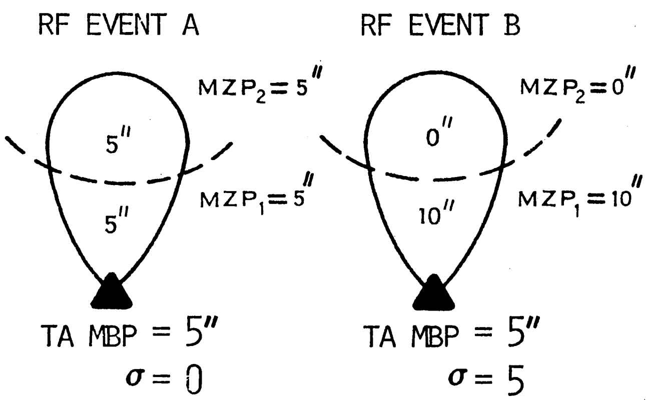
It should be stressed that RMS is probably dominated by high flow error. It requires numerous lower flow errors to equal the impact on the RMS of just one high flow error, so the RMS really cannot be considered a good statistic for judging model performance throughout the entire range of flows. For a simulation period of record, one may very well have only a single large storm which the model cannot reproduce, and the RMS will remain high even though most other rises and lower flows are reconstituted nicely.

7. The statistic Ratio is simply the computed RMS divided by OMDQ for all water years. A Ratio of less than 1.0 is generally considered

to be evidence of excellent simulation. Also, while comparing RMS between basins has little significance, comparing Ratios allows a reasonable one statistic comparison of model performance over any number of watersheds.

As pointed out in the introduction to this chapter, standard statistical measures as just discussed may or may not indicate the performance attributes of a distributed model (distributed input only or distributed input and distributed parameters). And one would hope that a distributed model, if reconstituting rises better than a lumped model, would also improve low flow simulation--or at least not detract from it. While statistics such as those so far mentioned may be inadequate to measure fully the impact on simulation performance of distributed mode operation, certain standard statistics are quite satisfactory in gaging low flow reconstitution. Obviously, one should choose a statistic that weights lower flows most heavily. Consequently, one could not seriously consider a statistic like RMS for the period of record. However, the average of the monthly MDQ, with error expressed by Percent Bias for the water years, is a statistic overwhelmingly dominated by the low flow regime. It, therefore, is the statistic that will be watched for signs of low flow deterioration during distributed mode reconstitution. A possibility considered but rejected is Percent Bias for given flow intervals. The problem here is defining properly the low flow regime in terms of absolute value (CFSD), when such a value may fluctuate greatly from season to season and year to year. One is faced with the probability of gathering so many bias statistics of differing values that a meaningful conclusion from the error analyses is impossible to draw. This is a real threat when dealing with no less than eight rivers with simulation periods in excess of five years. A careful analysis of published flows for the eight test basins indicates that streamflow falls within the recession category more than 90 percent of the time, which places storm flows in the "noise level" of the Percent Bias statistic.

A vexing problem arises when it is desired to measure closely the effect of multi-zone (distributed) modeling on higher flows generated by non-uniform rains. In this case, the standard statistics appear to largely fail, as such rises while terribly significant in the "real world," may be buried in the noise level of the statistics most relied on to gage high flow performance. Stated another way, the standard types of statistical summaries might fail to measure the improvement produced by a modeling technique (distributed model), since the improvement would probably be made in only a relatively small number of events. What is needed, then, is a test (a subject of this study) to include the development of an objective function (statistic) which would measure the effect one is attempting to produce. Since a refinement of this type might be expected to improve results only when the precipitation is non-uniform; it would be necessary to establish some measure of the variance of the zonal precipitation amounts and use this quantity as a weight to be applied to the discharge residuals (errors) when computing the statistical summations. The following statistic, suggested by Sittner(23), a weighted average error, $\bar{e}$, is offered, and will be discussed in conjunction with Figure 19.



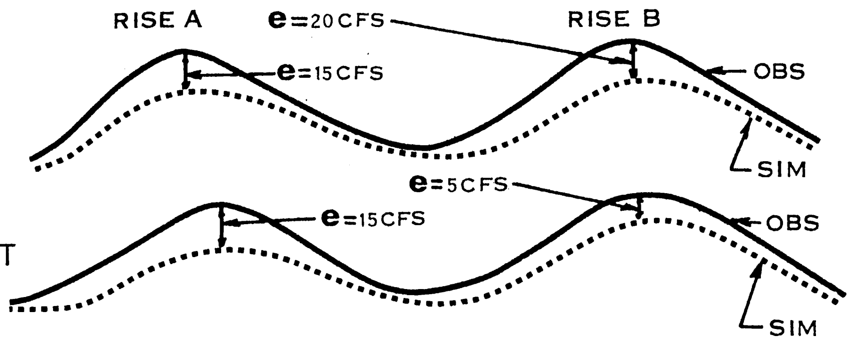
$$\sigma = \sqrt{\frac{\Sigma(x-\bar{x})^2}{N}}$$

$$\bar{e} = \frac{e_A \cdot \sigma_A + e_B \cdot \sigma_B}{\sigma_A + \sigma_B}$$

IF EACH ZONE HAS THE SAME MZP, $\sigma = 0$. THE GREATER THE DIFFEPENCE IN MZP, THE GREATER THE VALUE OF σ

LUMPED INPUT HYDROGRAPH

DISTRIBUTED INPUT HYDROGRAPH



THEN USING MZP VARIABILITY TO COMPUTE A WEIGHTED AVE:

EVENT A EVENT B

FOR LUMPED INPUT RUN: $\bar{e} = \dfrac{15 \cdot 0 + 20 \cdot 5}{5} = 20$ CFS

FOR DISTRIBUTED INPUT RUN $\bar{e} = \dfrac{15 \cdot 0 + 5 \cdot 5}{5} = 5$ CFS

WHICH INDICATES A MEASURE OF SIMULATION IMPROVEMENT AS A FUNCTION OF RF VARIABILITY.

SIMILARLY, A DISTRIBUTED INPUT-DISTRIBUTED PARAMETER SIMULATION RUN MAY BE EVALUATED.

Figure 19. Instantaneous Hydrograph Peak Error Analysis

$$\bar{e} = \frac{\sum_{1}^{N} e \cdot \sigma}{\sum_{1}^{N} \sigma} \tag{6.5}$$

where

$$\sigma = \left[\frac{\sum_{1}^{N} (x - \bar{x})^2}{N}\right]^{\frac{1}{2}}$$

Given a watershed divided into two or more zones, and a particular storm or rainfall (RF) event, a separate mean zone precipitation (MZP) is computed. The variation, then, of MZP across the watershed may be computed using the standard deviation, σ, where x is the MZP for a zone, $\bar{x}$ is the numerical average of the MZP values for all zones (noted in Figure 19 as total area mean basin precipitation - TA MBP), and N is the number of zones across the basin in question. If precipitation across the watershed is reasonably uniform, each zone will compute the same MZP, and the standard deviation will compute to zero. e is defined as the <u>absolute</u> difference between simulated peak flow and observed peak flow (difference in timing ignored) for a given rise along the river. Then, according to equation (6.5), the average peak error, $\bar{e}$, for all rises considered during the period of record would be the <u>weighted sum</u> of the individual error, e, divided by the sum of the weights. Figure 19 illustrates the technique given two storms over the same basin--rainfall events A and B resulting in rises A and B. In order to account for the variability of rainfall, the basin is divided into two zones, allowing for individual zone averaged precipitation values. Storm event generates a five-inch rainfall over each zone, so the rainfall is obviously uniform. However, storm event B is not uniform but rather a a heavy downstream rainfall resulting in an upper MZP of zero and a lower MZP of 10 inches. For event A, the TA MBP = (5 + 5)/2 = 5, and hence $\sigma = \left[[(5 - 5)^2 + (5 - 5)^2]/2\right]^{\frac{1}{2}} = 0$. For event B, the TA MBP = (0 + 10)/2 = 5, and hence $\sigma = \left[[(0 - 5)^2 + (10 - 5)^2]/2\right]^{\frac{1}{2}} = [50/2]^{\frac{1}{2}} = 5$.

Suppose one then runs the simulation model using total area averaged mean basin precipitation (lumped input) created originally as MBP input file to the <u>lumped model</u> (no zones considered), which generates two peak errors of 15 CFS and 20 CFS from storms A and B. Using this information plus our knowledge of the true variability of rainfall as measured by σ, a weighted average error of 20 CFS is computed for the lumped model simulation. Next, a simulation run is made using the MZP as distributed input to the <u>distributed model</u>, resulting in two peak errors of 15 CFS and 5 CFS for the storms A and B. From this one would tabulate a weighted average error of 5 CFS, indicating an improvement in simulation performance of 15 MFS. Similarly, one could make a third simulation run using both distributed input and distributed (zonally varied) parameters and compute a weighted average error. Since 6-hourly MZP and MBP is computed for input to the model, for the purposes of standard deviation computation, it was thought proper to total these means for a 24-hour period and use the 24-hour sums to arrive at a single σ value for the day. Most rises along the eight rivers investigated were generated by storms of duration one day or less.

It is obvious that rather than evaluate peak error using rainfall variability as weights, one could simply compute an average error of the peaks. For the lumped input run this would compute as (15 + 20)/2 = 17.5 CFS, and for the distributed input run (15 + 5)/2 = 10 CFS, again showing improvement in simulation performance due to a distributed model. However, the degree of improvement is not as pronounced, and one has no way of knowing whether or not only non-uniform storm generated rises were improved by the distributed input model, which is reasonable or also numerous uniform storm rises, which is not reasonable. The weighted average statistic filters out non-essential information, and assures a cause and effect relationship. Consequently, the same approach may be taken to analyze the impact of distributed mode simulation on uniform storms. Since there is always the possibility of degrading uniform storm simulation with a multi-zone model, the same statistic must be run, but using $1/\sigma$ as a weight. This then becomes a filter whereby the greater the rainfall variability, the less the weight. In order that the fraction not go to infinity, an arbitrary lower limit of $\sigma = 0.10$ was set.

The filtering of time series data through the use of weights is common in science and engineering. Weights may be used to smooth data or amplify data (the latter also called "desmoothing" or "inverse smoothing"), as is our case in evaluating, in part, the performance characteristics of a distributed hydrologic model. Instead of using the standard deviation of rainfall variability as a weight, one could use the mean deviation, a simpler statistic to compute. However, the standard deviation places greater emphasis on large deviations from the mean, a desirable feature, and therefore was considered more appropriate for filtering purposes. At the risk of becoming redundant, it should be stressed that the weighted average magnifies the reduction in errors brought about by distributed model simulation. It is a necessary step required by the fact that when analyzing numerous errors in a typical simulation run, one is dealing with many storms of small magnitude and with uniform rainfall characteristics. Thus, a non-weighted approach to error analysis could result in the statistic being drowned out, so to speak, by insignificant changes in simulation. The weighted average places emphasis on those few but most significant events which would be most critical in ascertaining change in simulation performance brought about by a multi-zone hydrologic model.

The weighted peak error in analyzing non-uniform storm rises will be noted by $\bar{e}_n$, and uniform storm rises by $\bar{e}_u$, with the analysis performed on all selected rises stored as instantaneous flow ordinates (6-hourly) in the hydrologic model input data set (instantaneous flows on separate magnetic tape). It is not sufficient, however, to measure only the magnitude of the peak when evaluating distributed model performance. The model may also change peak timing and runoff volumes, so these hydrograph properties must be gaged. Consequently each rise defined by instantaneous ordinates of flow was examined and the time-of-peak tabulated. Then runoff volumes were measured, considering total volume beneath the hydrograph from initial-point-of simulated rise to an arbitrary point "x-days" beyond simulated peak. Volumes under the corresponding observed rises were similarly computed. Again, the filtering statistic (weighted average) may be called on for error analyses use. Storm timing errors were computed as the number of hours (0, 6, 12, etc.) the simulated peak is displaced from the corresponding observed peak. This number was then multiplied by the associated measusre of rainfall variability (σ or $1/\sigma$) according to the filtering statistic, and a weighted average of timing errors computed for the period of record. Similarly, a weighted average for storm runoff volume error (difference between observed and simulated volume) was calculated. Let $\bar{T}_n$ and $\bar{T}_u$ denote the weighted average of timing errors, and $\bar{V}_n$ and $\bar{V}_u$ denote the weighted average of volume errors, for non-uniform or uniform storms, respectively. Data for these performance indices, expressed in terms of percent reduction in error (-) or percent increase in error (+) due to multi-zone modeling, are presented in Table XXXIV, and will be discussed later.

In order to further judge the degree of simulation change as a function of rainfall variability brought about by the multi-zone model, it could be instructive to plot the individual storm errors versus the associated variation in rainfall, no weighting included. For this purpose, one might consider an error function of the form:

$$eI = \frac{e_L - e_D}{e_L} \cdot 100$$

Considering, for the moment, e_L as a storm peak error for lumped model, e_D as storm peak error for the distributed model, then e_I becomes the percent improvement in peak flow simulation due to multi-zone operation, for any given storm event. If e_I is positive, the error between distributed model peak and observed peak is less than the error realized when simulating in lumped mode. So the greater the improvement in simulation due to the distributed model, the larger the value of e_I. Conversely, the greater the degradation in peak flow brought about by multi-zone model simulation, the greater the negative value of e_I. The same approach may be taken to compute, for plotting, an index to errors in storm timing and storm volume. In these two cases, one must use in the error statistic the storm timing error or the storm volume error, based on lumped and distributed mode simulation runs. If e_I is the percent improvement (+) in peak flow reconstitution for a storm due to distributed model mode simulation, then let T_I indicate percent timing improvement and V_I denote percent volume improvement. Again, any negative value indicates that the distributed model produced a degradation in simulation, as measured by the performance index. Figures 21 through 26 display these data as a function of the storm rainfall variability and will be discussed later.

Before discussing calibration, a few comments are in order regarding the analysis of complex rises--rises that exhibit two or more peaks generated by multiple bursts of rain that may occur over several days. There were only a few such storms to be concerned with, fortunately. Only one crest was considered (the highest), and runoff volume under the hydrograph was computed for total storm runoff, just as the case for single-peak rises. And the standard deviation was computed on the basis of storm total MBP and storm total MZP.

Calibration

The success of a general hydrologic model is measued by its ability to simulate streamflows that match observed records. The model input consists of time sequences of climatological data and a set of values for model parameters. These model parameters relate theoretically to watershed physical characteristics, and operationally those values are estimated by a sequence of trials and adjustments ending in an acceptable flow match. The quality of a given trial is determined by the closeness with which the observed and simulated flows agree during <u>every</u> simulation period. The manifest impracticality of making <u>all</u> of these comparisons in evaluating a trial simulation requires the selection of a small number of indices (statistics), as discussed in the previous section of this chapter, to measure simulation accuracy. One such index is mean daily flow for the water year, or all water years. However, a large number of combinations of parameter values will give the same annual mean. Therefore, one must differentiate in selecing among these combinations by adding other indices such as room mean square error, correlation coefficients, hydrograph characteristics, etc. If one is to adjust a trial set of model parameter values in order to improve the matching of the observed and simulated streamflows, he must be aware of the effect a given parameter change on simulated streamflow. In other words, the modeler must have a feeling for parameter sensitivity, which comes only through experience in model fitting. Rational manual adjustments to the "key" or most sensitive parameters expedite the calibration process, but by no means guarantee a final product of accurate simulation across the <u>entire</u> period of record. The only guidance the hydrologist has is a rough idea of a reasonable range of possible parameter values based on other calibrations for nearby basins, or knowledge of the physical characteristics of the watershed to be modeled. Through sensitivity analysis the modeler soon learns which parameters need to be estimated carefully, and which require only rough approximation.

The simulated versus observed hydrograph files generated by the hydrologic model program are generally termed validation or verification output. For each of the eight test basins, multiyear simulation was generated, the synthesized streamflow results compared with observed streamflow, and statistical analyses of the results printed out in tabular form. While peak magnitude and timing are the primary basis for judging the effectiveness of the model with respect to storm events, other multiyear statistics, as discussed in detail previously in this chapter, serve as the basis of determining overall model performance. Table XIII displays the 12 monthly PE adjustment factors used in the verification runs. Tables XIV through XXI indicate model parameters used, and Tables XXII through XXXIII present simulation multiyear statistical summaries. The particular statistics required for additional multi-zone model evaluation are shown in Table XXXIV. All tables will be discussed individually in later sections.

Testing a distributed model first requires a total area (no zones, lumped input-lumped parameters) catchment calibration to compare against, since the object of the research is to determine whether or not the created multi-zone model will in fact out-perform the total are model, at least under non-uniform rainfall conditions. And, as pointed out previously in this report, the distributed model may take two forms: a simple distributed rainfall input with the same parameter set established for each zone, or a distributed input-distributed parameter structure whereby the model not only utilizes zonally varied rainfall, but also differing parameter sets in each zone. So the model, then, may be viewed as being run in any one of the stated three forms or modes. Figure 20 illustrates pictorially the sequence of events when running a two-zone distributed model. Comparing the illustration with what would be true for a total area catchment model instead of a 1-inch versus 2-inch zonal rainfall distribution, the mean basin

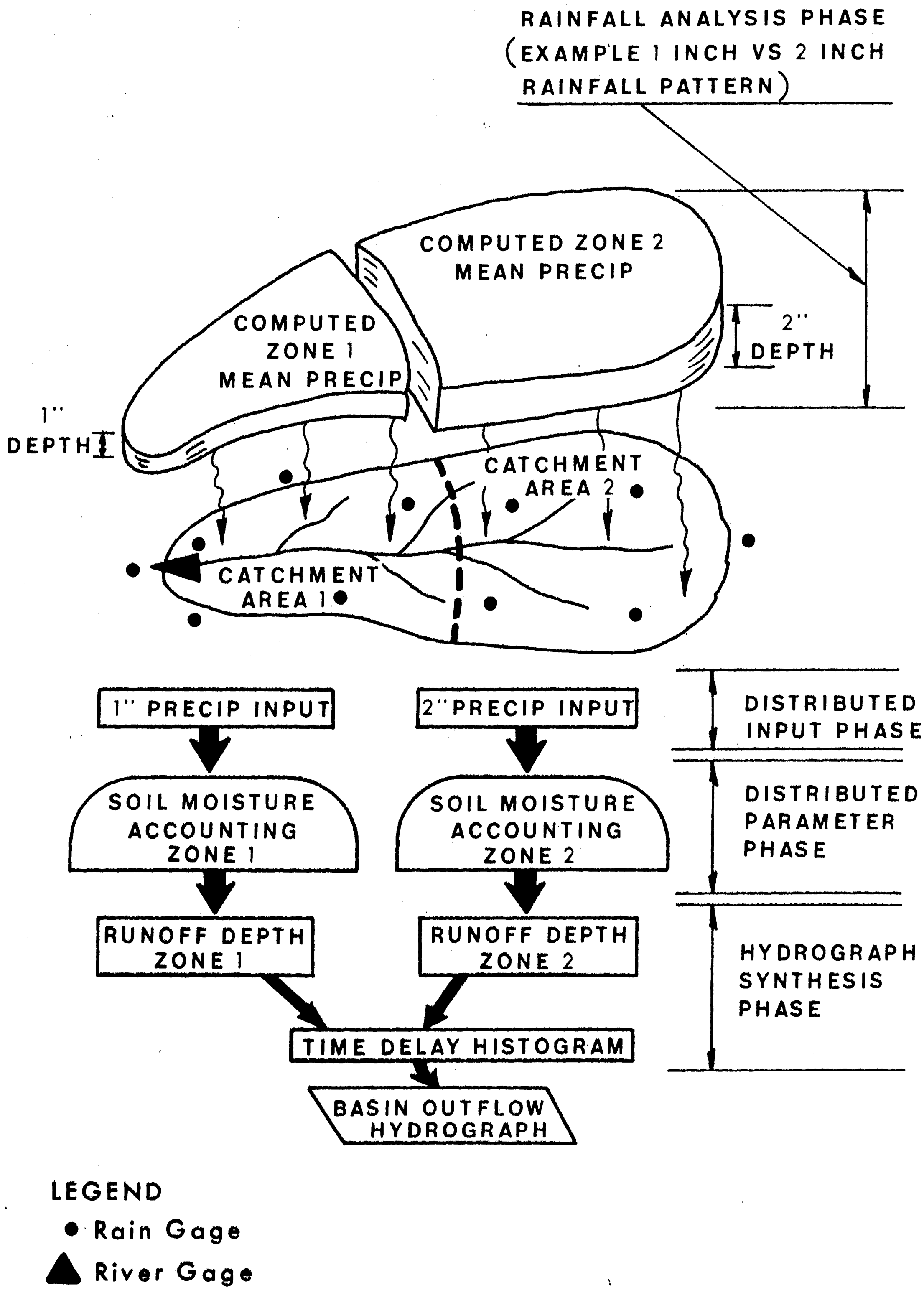


Figure 20. Pictorial Illustration of Distributed Model Operation

precipitation would compute near 1.5 inches. And instead of soil moisture accounting being performed by the model over two zones, the accounting would be maintained over the total catchmen area using the 1.5-inch MBP. What is noted in Figure 20 as distributed parameter phase is true only if the parameter sets in each zone differ. Otherwise, soil moisture values will be determined entirely through distributed precipitation inputs. And as will be demonstrated shortly, the hydrograph generated by runoff depths may change significantly according to which mode the hydrologic model is running in. The following sections describe model calibration strategy and present results as measured by standard multiyear statistical summaries of mean daily flow data.

Total Catchment Area

Not only is a total catchment area lumped model calibration necessary, so as to provide base statistics to compare a distributed model against, but the final lumped set of parameters serve as initial parameters to the distributed model. Also, a lumped model calibration is within the model fitting skill range of most hydrologists, whereas the best procedure for fitting a multi-zone model to a watershed is unknown. Therefore, one must question the precision with which it is possible to determine physically realistic multi-zone parameters in the absence of total catchment area calibration.

After deriving most initial parameters from observed hydrographs, as discussed earlier in Chapter V, an average of 15 trial-and-error calibration runs were made on each of the eight test watersheds before a final fit was declared. Table XIII lists the monthly PE adjustment

TABLE XIII

BASIN CALIBRATION PE MONTHLY ADJUSTMENT FACTORS

J	F	M	A	M	J	J	A	S	O	N	D
				FAYETTEVILLE							
0.72	0.83	0.84	0.84	0.87	0.88	0.90	0.92	0.92	0.93	0.84	0.76
				IMBODEN							
0.90	0.85	0.80	0.80	0.80	0.85	0.95	1.10	1.10	1.10	1.00	1.00
				PATTERSON							
1.15	0.75	0.55	0.50	1.00	1.30	1.35	1.40	1.50	1.40	1.20	1.20
				LAUREL							
1.10	0.80	0.70	0.70	0.90	0.97	1.10	1.15	1.03	1.20	1.15	1.20
				COLLINS							
0.90	0.90	0.90	0.88	1.01	1.09	1.08	1.10	1.12	1.13	1.03	0.95
				EDINBURG							
0.90	1.00	0.95	0.85	0.90	1.08	1.05	1.04	1.06	1.05	0.99	0.99
				GLENMORA							
1.00	0.93	0.90	0.95	0.98	1.05	1.10	1.20	1.30	1.20	1.20	1.15
				OBERLIN							
1.00	0.93	0.90	0.95	0.98	1.05	1.10	1.20	1.30	1.20	1.20	1.15

factors obtained from calibration, and were used unaltered for later multi-zone simulation runs. Tables XIV through XXI, in the total area (TA) column, list initial and final parameter values for the eight basins. Tables XXII through XXV present the performance data for final calibration. Simulated mean, observed mean, RMS, and maximum error are in CFSD units (i.e., mean daily flow). Each basin exhibits good water balance, as judged by the closeness of the means for all water years. With the exception of Patterson and Glenmora, Ratios are less than 1.0, water year Correlation Coefficient greater than 0.9, and water year Bias less than 2.0 percent, leading to the conclusion that overall simulation produced by the lumped model for six basins is very good. The simulation obtained for Patterson is only fair, and Glenmora is best judged as poor. Obviously, the model has difficulty reconstituting daily streamflow for those two watersheds, regardless of the fact that close water balances were achieved for the total period of record.

Distributed Input

Attention was next turned to the possibility of improving simulation through the use of multi-zone distributed rainfall input, though still maintaining identical parameter sets in each zone. The final parameter values for basin total area (TA) calibration were used as initial calibration values to each basin zone. It must be first stressed, however, that the prior TA calibrations used, as input data, mean basin precipitation. And for multi-zone runs, an effort must be made to establish parameters optimum for distributed input mode simulation (some simulation error can be attributed to the use of TA lumped rainfall input data, which would be reflected in the parameter values

TABLE XIV

FAYETTEVILLE BASIN SIMULATION MODEL CALIBRATION

	Initial Value TA	Z1	Z2	Z3	Final Value TA	Z1	Z2	Z3
***	TA	Z1	Z2	Z3	TA	Z1	Z2	Z3
UPPER ZONE AND IMPERVIOUS AREA PARAMETERS								
* PX-ADJ (%)	1.0	1.0	1.0		1.0	1.0	1.0	
PE-ADJ (%)	1.0	0.9	0.9		1.0	0.9	0.9	
(1) UZTWM (IN)	1.6	1.4	1.4		1.3	1.6	1.2	
(2) UZFWM (IN)	1.1	1.0	1.0		1.0	1.4	.60	
UZK (RATIO)	.535	.369	.369		.369	.369	.369	
PCTIM (%)	.00	.02	.02		.01	.01	.03	
(6) ADIMP (%)	.03	.04	.04		.04	.03	.06	
SARVA (%)	.01	.03	.03		.03	.03	.03	
PERCOLATION AND LOWER ZONE PARAMETERS								
ZPERC (%)	75.	20.	30.		12.	20.	20.	
REXP (EXPONENT)	2.0	2.6	2.6		2.6	2.6	2.6	
PBASE (IN)	.20	.21	.21		.21	.24	.19	
(3) LZTWM (IN)	2.9	2.3	2.3		2.0	2.8	1.8	
(4) LZFSM (IN)	2.3	2.8	2.8		2.8	3.1	2.5	
(5) LZFPM (IN)	4.8	3.5	3.5		3.5	4.0	3.0	
LZSK (%)	.065	.065	.065		.065	.065	.065	
LZPK (%)	.009	.009	.009		.009	.009	.009	
PFREE (%)	.30	.30	.30		.30	.50	.20	
RESV (%)	.50	.45	.45		.45	.60	.30	
SIDE (RATIO)	0	0	0		0	0	0	
SSOUT (CFS)	0	0	0		0	0	0	
** KS1 (HRS)	3.1				4.0			
SOIL MOISTURE VARIABLE INITIAL VALUES (STORAGE CONTENTS)								
(1) UZTWC	1.4	.83	.83		.83	.80	.40	
(2) UZFWC	0	0	0		0	0	0	
(3) LZTWC	2.3	1.4	1.4		1.4	1.4	1.0	
(4) LZFSC	0	0	0		0	0	0	
(5) LZFPC	1.5	1.3	1.3		1.3	1.3	1.3	
(6) ADIMC (IN)	3.1	2.1	2.1		2.1	2.1	2.1	

*** TA (TOTAL AREA) Z (ZONE)
* ALL PERCENTAGE UNITS (%) SHOWN IN FRACTIONAL VALUE (%/100)
** TIME-DELAY HISTOGRAM STORAGE CONSTANT K

TABLE XV

IMBODEN BASIN SIMULATION MODEL CALIBRATION

***	Initial Value TA	Initial Value Z1	Initial Value Z2	Initial Value Z3	Final Value TA	Final Value Z1	Final Value Z2	Final Value Z3
UPPER ZONE AND IMPERVIOUS AREA PARAMETERS								
* PX-ADJ (%)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
PE-ADJ (%)	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9
(1) UZTWM (IN)	1.2	3.6	3.6	3.6	4.3	4.2	3.0	2.8
(2) UZFWM (IN)	0.3	1.2	1.2	1.2	0.3	1.5	1.0	0.9
UZK (RATIO)	.585	.685	.685	.685	.685	.685	.685	.685
PCTIM (%)	.00	.01	.01	.01	.01	.01	.02	.02
(6) ADIMP (%)	.07	.04	.04	.04	.04	.03	.05	.06
SARVA (%)	.03	.05	.05	.05	.05	.05	.05	.05
PERCOLATION AND LOWER ZONE PARAMETERS								
ZPERC (%)	64.	92.	92.	92.	92.	92.	92.	92.
REXP (EXPONENT)	2.5	2.2	2.2	2.2	2.2	2.2	2.2	2.2
PBASE (IN)	.22	.11	.11	.11	.11	.16	.10	.08
(3) LZTWM (IN)	4.0	6.5	6.5	6.5	6.5	7.5	5.5	4.0
(4) LZFSM (IN)	3.1	1.6	1.6	1.6	1.6	2.3	1.5	1.2
(5) LZFPM (IN)	5.9	7.8	7.8	7.8	7.8	8.5	6.0	4.0
LZSK (%)	.066	.065	.065	.065	.065	.065	.065	.065
LZPK (%)	.003	.001	.001	.001	.001	.001	.001	.001
PFREE (%)	.50	.40	.40	.40	.45	.60	.35	.20
RESV (%)	.30	.30	.30	.30	.30	.40	.25	.10
SIDE (RATIO)	0	0	0	0	0	0	0	0
SSOUT (CFS)	-371	-371	-371	-371	-371	-371	-371	-371
** KS1 (HRS)	4.0				4.0			
SOIL MOISTURE VARIABLE INITIAL VALUES (STORAGE CONTENTS)								
(1) UZTWC	.39	2.7	2.7	2.7	2.7	2.0	1.5	1.2
(2) UZFWC	0	0	0	0	0	0	0	0
(3) LZTWC	.59	3.9	3.9	3.9	3.9	4.3	3.3	2.5
(4) LZFSC	0	0	0	0	0	0	0	0
(5) LZFPC	2.3	5.3	5.3	5.3	5.3	4.2	3.0	2.0
(6) ADIMC (IN)	1.7	2.9	2.9	2.9	2.9	2.9	2.9	2.9

*** TA (TOTAL AREA) Z (ZONE)
* ALL PERCENTAGE UNITS (%) SHOWN IN FRACTIONAL VALUE (%/100)
** TIME-DELAY HISTOGRAM STORAGE CONSTANT K

TABLE XVI

PATTERSON BASIN SIMULATION MODEL CALIBRATION

	Initial Value				Final Value			
***	TA	Z1	Z2	Z3	TA	Z1	Z2	Z3
UPPER ZONE AND IMPERVIOUS AREA PARAMETERS								
* PX-ADJ (%)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
PE-ADJ (%)	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
(1) UZTWM (IN)	3.9	2.3	2.3	2.3	2.5	3.5	2.5	1.5
(2) UZFWM (IN)	1.0	1.4	1.4	1.4	1.1	1.8	1.3	0.7
UZK (RATIO)	.280	.410	.410	.410	.437	.437	.437	.437
PCTIM (%)	.03	.01	.01	.01	.00	.00	.02	.04
(6) ADIMP (%)	.06	.08	.08	.08	.08	.06	.08	.10
SARVA (%)	.13	.13	.13	.13	.13	.13	.13	.13
PERCOLATION AND LOWER ZONE PARAMETERS								
ZPERC (%)	10.	88.	88.	88.	88.	88.	88.	88.
REXP (EXPONENT)	4.0	2.6	2.6	2.6	2.6	2.6	2.6	2.6
PBASE (IN)	.42	.06	.06	.06	.06	.11	.07	.05
(3) LZTWM (IN)	4.7	3.1	3.1	3.1	2.7	4.0	3.0	2.0
(4) LZFSM (IN)	2.3	2.1	2.1	2.1	2.1	3.7	2.2	1.5
(5) LZFPM (IN)	4.9	3.7	3.7	3.7	3.7	4.7	3.5	2.5
LZSK (%)	.138	.027	.027	.027	.027	.027	.027	.027
LZPK (%)	.019	.002	.002	.002	.002	.002	.002	.002
PFREE (%)	.30	.40	.40	.40	.45	.50	.35	.20
RESV (%)	.30	.30	.30	.30	.30	.40	.30	.20
SIDE (RATIO)	0	0	0	0	0	0	0	0
SSOUT (CFS)	0	0	0	0	0	0	0	0
** KS1 (HRS)	4.0				4.0			
SOIL MOISTURE VARIABLE INITIAL VALUES (STORAGE CONTENTS)								
(1) UZTWC	0.7	1.3	1.3	1.3	1.3	1.7	1.2	0.7
(2) UZFWC	0	0	0	0	0	0	0	0
(3) LZTWC	1.5	1.5	1.5	1.5	1.5	2.0	1.5	1.0
(4) LZFSC	0	0	0	0	0	0	0	0
(5) LZFPC	0.5	3.0	3.0	3.0	3.5	2.3	1.7	1.2
(6) ADIMC (IN)	2.3	2.7	2.7	2.7	2.7	2.7	2.7	2.7

*** TA (TOTAL AREA) Z (ZONE)

* ALL PERCENTAGE UNITS (%) SHOWN IN FRACTIONAL VALUE (%/100)

** TIME-DELAY HISTOGRAM STORAGE CONSTANT K

TABLE XVII

LAUREL BASIN SIMULATION MODEL CALIBRATION

***	Initial Value TA	Initial Value Z1	Initial Value Z2	Initial Value Z3	Final Value TA	Final Value Z1	Final Value Z2	Final Value Z3
UPPER ZONE AND IMPERVIOUS AREA PARAMETERS								
* PX-ADJ (%)	1.0	1.0	1.0		1.0	1.0	1.0	
PE-ADJ (%)	1.0	0.9	0.9		1.0	0.9	0.9	
(1) UZTWM (IN)	1.5	2.0	2.0		2.3	3.0	1.0	
(2) UZFWM (IN)	1.3	1.6	1.6		1.3	2.2	1.0	
UZK (RATIO)	.592	.318	.318		.318	.318	.318	
PCTIM (%)	.01	.01	.01		.01	.01	.02	
(6) ADIMP (%)	.04	.06	.06		.06	.03	.09	
SARVA (%)	.10	.04	.04		.04	.04	.04	
PERCOLATION AND LOWER ZONE PARAMETERS								
ZPERC (%)	30.	32.	32.		32.	32.	32.	
REXP (EXPONENT)	3.0	3.2	3.2		3.2	3.2	3.2	
PBASE (IN)	.23	.12	.12		.12	.16	.09	
(3) LZTWM (IN)	6.3	5.0	5.0		5.4	6.0	4.0	
(4) LZFSM (IN)	1.9	1.2	1.2		1.2	1.6	1.0	
(5) LZFPM (IN)	3.1	2.9	2.9		2.9	4.0	2.0	
LZSK (%)	.092	.082	.082		.082	.082	.082	
LZPK (%)	.015	.006	.006		.006	.006	.006	
PFREE (%)	.30	.30	.30		.25	.40	.20	
RESV (%)	.30	.30	.30		.30	.40	.15	
SIDE (RATIO)	0	0	0		0	0	0	
SSOUT (CFS)	0	0	0		0	0	0	
** KS1 (HRS)		6.5				6.5		
SOIL MOISTURE VARIABLE INITIAL VALUES (STORAGE CONTENTS)								
(1) UZTWC	0.3	0.7	0.7		0.7	1.5	0.5	
(2) UZFWC	0	0	0		0	0	0	
(3) LZTWC	1.1	1.1	1.1		1.1	3.1	2.0	
(4) LZFSC	0	0	0		0	0	0	
(5) LZFPC	0.5	1.3	1.3		1.3	2.0	1.0	
(6) ADIMC (IN)	1.5	2.3	2.3		2.3	2.3	2.3	

*** TA (TOTAL AREA) Z (ZONE)

* ALL PERCENTAGE UNITS (%) SHOWN IN FRACTIONAL VALUE (%/100)

** TIME-DELAY HISTOGRAM STORAGE CONSTANT K

TABLE XVIII

COLLINS BASIN SIMULATION MODEL CALIBRATION

	Initial Value				Final Value			
***	TA	Z1	Z2	Z3	TA	Z1	Z2	Z3
UPPER ZONE AND IMPERVIOUS AREA PARAMETERS								
* PX-ADJ (%)	1.0	1.0	1.0		1.0	1.0	1.0	
PE-ADJ (%)	1.0	0.9	0.9		1.0	0.9	0.9	
(1) UZTWM (IN)	3.3	2.3	2.3		2.5	3.3	1.6	
(2) UZFWM (IN)	1.7	1.9	1.9		1.7	2.6	1.2	
UZK (RATIO)	.280	.403	.403		.403	.403	.403	
PCTIM (%)	.03	.01	.01		.01	.01	.01	
(6) ADIMP (%)	.060	.060	.060		.042	.090	.030	
SARVA (%)	.035	.015	.015		.015	.015	.015	
PERCOLATION AND LOWER ZONE PARAMETERS								
ZPERC (%)	45.	65.	65.		65.	65.	65.	
REXP (EXPONENT)	1.8	1.8	1.8		1.8	1.8	1.8	
PBASE (IN)	.17	.12	.12		.12	.15	.10	
(3) LZTWM (IN)	5.1	5.0	5.0		5.3	6.0	4.0	
(4) LZFSM (IN)	1.4	1.2	1.2		1.2	1.6	1.0	
(5) LZFPM (IN)	4.3	3.5	3.5		3.5	4.0	3.0	
LZSK (%)	.100	.078	.078		.078	.078	.078	
LZPK (%)	.007	.006	.006		.006	.006	.006	
PFREE (%)	.30	.30	.30		.30	.04	.02	
RESV (%)	.30	.30	.30		.30	.04	.02	
SIDE (RATIO)	0	0	0		0	0	0	
SSOUT (CFS)	0	0	0		0	0	0	
** KS1 (HRS)		4.0				4.0		
SOIL MOISTURE VARIABLE INITIAL VALUES (STORAGE CONTENTS)								
(1) UZTWC	1.5	1.9	1.9		1.9	1.6	0.8	
(2) UZFWC	0	0	0		0	0	0	
(3) LZTWC	2.3	1.7	1.7		1.7	3.0	2.0	
(4) LZFSC	0	0	0		0	0	0	
(5) LZFPC	1.9	1.3	1.3		1.3	2.0	1.5	
(6) ADIMC (IN)	4.1	4.1	4.1		4.1	4.1	4.1	

*** TA (TOTAL AREA) Z (ZONE)
* ALL PERCENTAGE UNITS (%) SHOWN IN FRACTIONAL VALUE (%/100)
** TIME-DELAY HISTOGRAM STORAGE CONSTANT K

TABLE XIX

EDINBURG BASIN SIMULATION MODEL CALIBRATION

***	Initial Value TA	Z1	Z2	Z3	Final Value TA	Z1	Z2	Z3
UPPER ZONE AND IMPERVIOUS AREA PARAMETERS								
* PX-ADJ (%)	1.0	1.0	1.0		1.0	1.0	1.0	
PE-ADJ (%)	1.0	0.9	0.9		1.0	0.9	0.9	
(1) UZTWM (IN)	2.9	3.5	3.5		3.7	4.0	3.0	
(2) UZFWM (IN)	1.9	1.7	1.7		1.1	2.2	1.3	
UZK (RATIO)	.175	.245	.245		.245	.245	.245	
PCTIM (%)	.02	.02	.02		.01	.01	.03	
(6) ADIMP (%)	.03	.01	.01		.01	.00	.03	
SARVA (%)	.03	.03	.03		.03	.03	.03	
PERCOLATION AND LOWER ZONE PARAMETERS								
ZPERC (%)	8.0	20.	20.		6.0	20.	20.	
REXP (EXPONENT)	1.8	1.5	1.5		1.2	1.5	1.5	
PBASE (IN)	.05	.20	.20		.20	.25	.16	
(3) LZTWM (IN)	4.7	4.5	4.5		4.5	6.0	3.5	
(4) LZFSM (IN)	0.7	1.2	1.2		1.2	1.5	1.0	
(5) LZFPM (IN)	1.9	1.8	1.8		1.8	2.2	1.3	
LZSK (%)	.047	.150	.150		.150	.150	.150	
LZPK (%)	.005	.009	.009		.009	.009	.009	
PFREE (%)	0	.20	.20		0	.30	.10	
RESV (%)	.30	.30	.30		.30	.40	.20	
SIDE (RATIO)	0	0	0		0	0	0	
SSOUT (CFS)	0	0	0		0	0	0	
** KS1 (HRS)	5.2				3.1			
SOIL MOISTURE VARIABLE INITIAL VALUES (STORAGE CONTENTS)								
(1) UZTWC	2.1	2.3	2.3		2.3	2.0	1.5	
(2) UZFWC	0	0	0		0	0	0	
(3) LZTWC	0.9	1.9	1.9		1.9	3.0	1.7	
(4) LZFSC	0	0	0		0	0	0	
(5) LZFPC	1.3	1.1	1.1		1.1	1.2	0.7	
(6) ADIMC (IN)	3.9	4.9	4.9		4.9	4.9	4.9	

*** TA (TOTAL AREA) Z (ZONE)
* ALL PERCENTAGE UNITS (%) SHOWN IN FRACTIONAL VALUE (%/100)
** TIME-DELAY HISTOGRAM STORAGE CONSTANT K

TABLE XX

GLENMORA BASIN SIMULATION MODEL CALIBRATION

***	Initial Value TA	Initial Value Z1	Initial Value Z2	Initial Value Z3	Final Value TA	Final Value Z1	Final Value Z2	Final Value Z3
UPPER ZONE AND IMPERVIOUS AREA PARAMETERS								
* PX-ADJ (%)	1.0	1.0	1.0		1.0	1.0	1.0	
PE-ADJ (%)	1.0	.90	.90		1.0	.90	.90	
(1) UZTWM (IN)	4.1	5.0	5.0		5.9	6.0	4.0	
(2) UZFWM (IN)	5.9	8.2	8.2		9.8	9.2	7.0	
UZK (RATIO)	.250	.250	.250		.250	.250	.250	
PCTIM (%)	.00	.00	.00		.00	.00	.00	
(6) ADIMP (%)	.01	.05	.05		.05	.03	.08	
SARVA (%)	.01	.01	.01		.01	.01	.01	
PERCOLATION AND LOWER ZONE PARAMETERS								
ZPERC (%)	0.5	10.	10.		2.0	10.	10.	
REXP (EXPONENT)	5.0	3.1	3.1		5.0	3.1	3.1	
PBASE (IN)	.77	.77	.77		.77	.88	.57	
(3) LZTWM (IN)	6.3	6.0	6.0		4.7	8.0	4.0	
(4) LZFSM (IN)	10.6	10.6	10.6		10.6	12.	8.0	
(5) LZFPM (IN)	8.7	8.7	8.7		8.7	11.	6.0	
LZSK (%)	.064	.064	.064		.064	.064	.064	
LZPK (%)	.010	.010	.010		.010	.010	.010	
PFREE (%)	.30	.30	.30		.30	.40	.20	
RESV (%)	.30	.30	.30		.30	.40	.20	
SIDE (RATIO)	0	0	0		0	0	0	
SSOUT (CFS)	0	0	0		0	0	0	
** KS1 (HRS)		3.1				3.1		
SOIL MOISTURE VARIABLE INITIAL VALUES (STORAGE CONTENTS)								
(1) UZTWC	0.7	1.4	1.4		0.7	2.0	1.0	
(2) UZFWC	0	0	0		0	0	0	
(3) LZTWC	2.3	2.8	2.8		2.3	4.0	2.0	
(4) LZFSC	0	0	0		0	0	0	
(5) LZFPC	0.5	2.0	2.0		0.5	3.0	1.5	
(6) ADIMC (IN)	1.9	3.0	3.0		1.9	3.0	3.0	

*** TA (TOTAL AREA) Z (ZONE)
* ALL PERCENTAGE UNITS (%) SHOWN IN FRACTIONAL VALUE (%/100)
** TIME-DELAY HISTOGRAM STORAGE CONSTANT K

TABLE XXI

OBERLIN BASIN SIMULATION MODEL CALIBRATION

	Initial Value				Final Value			
***	TA	Z1	Z2	Z3	TA	Z1	Z2	Z3
UPPER ZONE AND IMPERVIOUS AREA PARAMETERS								
* PX-ADJ (%)	1.0	1.0	1.0		1.0	1.0	1.0	
PE-ADJ (%)	1.0	0.9	0.9		1.0	.90	.90	
(1) UZTWM (IN)	2.3	2.8	2.8		1.9	3.3	2.3	
(2) UZFWM (IN)	1.3	2.1	2.1		1.3	2.7	1.5	
UZK (RATIO)	.226	.226	.226		.226	.226	.226	
PCTIM (%)	.02	.02	.02		.02	.02	.03	
(6) ADIMP (%)	.35	.35	.35		.35	.02	.04	
SARVA (%)	.00	.02	.02		.02	.02	.02	
PERCOLATION AND LOWER ZONE PARAMETERS								
ZPERC (%)	1.9	10.	10.		3.9	10.	10.	
REXP (EXPONENT)	1.0	3.1	3.1		2.0	3.1	3.1	
PBASE (IN)	.54	.54	.54		.54	.61	.47	
(3) LZTWM (IN)	9.0	6.8	6.8		7.8	7.6	6.0	
(4) LZFSM (IN)	4.7	4.7	4.7		4.7	5.4	4.0	
(5) LZFPM (IN)	7.8	7.8	7.8		7.8	8.9	7.0	
LZSK (%)	.064	.064	.064		.064	.064	.064	
LZPK (%)	.030	.030	.030		.030	.030	.030	
PFREE (%)	.30	.30	.30		.30	.40	.20	
RESV (%)	.30	.30	.30		.30	.40	.20	
SIDE (RATIO)	0	0	0		0	0	0	
SSOUT (CFS)	0	0	0		0	0	0	
** KS1 (HRS)	3.1				3.1			
SOIL MOISTURE VARIABLE INITIAL VALUES (STORAGE CONTENTS)								
(1) UZTWC	0.7	1.4	1.4		0.7	1.3	0.8	
(2) UZFWC	0	0	0		0	0	0	
(3) LZTWC	2.7	2.7	2.7		2.7	3.5	2.5	
(4) LZFSC	0	0	0		0	0	0	
(5) LZFPC	0.3	2.0	2.0		0.3	1.8	1.3	
(6) ADIMC (IN)	1.5	3.0	3.0		1.5	3.0	3.0	

*** TA (TOTAL AREA) Z (ZONE)
* ALL PERCENTAGE UNITS (%) SHOWN IN FRACTIONAL VALUE (%/100)
** TIME-DELAY HISTOGRAM STORAGE CONSTANT K

TABLE XXII

TOTAL AREA CATCHMENT MODEL FINAL CALIBRATION STATISTICS, FAYETTEVILLE AND IMBODEN BASINS

MULTIYEAR STATISTICAL SUMMARY

MONTH	SIMULATED MEAN	OBSERVED MEAN	PERCENT BIAS	MAXIMUM ERROR	CORREL. COEFF.
BASIN: FAYETTEVILLE					
OCTOBER	531	377	40.96	5286	0.796
NOVEMBER	820	685	19.58	3228	.887
DECEMBER	2081	1730	20.31	15077	.935
JANUARY	2192	2049	6.98	-6205	.947
FEBRUARY	2199	2346	-6.28	6742	.952
MARCH	2068	2333	-11.34	-4322	.961
APRIL	1938	2335	-17.02	-4987	.948
MAY	1686	2024	-16.70	-8890	.866
JUNE	610	676	-9.72	-1444	.818
JULY	658	591	11.39	2670	.878
AUGUST	471	415	13.44	1952	.619
SEPTEMBER	438	361	21.27	2058	.606
WATER YEARS	1305	1332	-1.34	15077	0.922
BEST FIT LINE: A = 5.275 B = 0.871					
RMS = 859 RATIO = 0.645					
BASIN: IMBODEN					
OCTOBER	829	771	7.60	-1085	0.926
NOVEMBER	963	1061	-9.24	2150	.950
DECEMBER	2080	2204	-5.62	-4013	.979
JANUARY	2159	2252	-4.14	-6356	.981
FEBRUARY	1840	1962	-6.22	4713	.929
MARCH	1853	1961	-5.54	5542	.945
APRIL	2693	2506	7.44	6533	.967
MAY	1781	1917	-7.12	-6490	.866
JUNE	1088	985	10.47	7262	.574
JULY	592	622	-4.86	-349	.496
AUGUST	971	703	38.04	9356	.954
SEPTEMBER	997	749	33.19	4845	.936
WATER YEARS	1485	1472	0.86	9356	0.934
BEST FIT LINE: A = 5.63 B = 0.858					
RMS = 883 RATIO = 0.595					

TABLE XXIII

TOTAL AREA CATCHMENT MODEL FINAL CALIBRATION STATISTICS, PATTERSON AND LAUREL

MULTIYEAR STATISTICAL SUMMARY

MONTH	SIMULATED MEAN	OBSERVED MEAN	PERCENT BIAS	MAXIMUM ERROR	CORREL. COEFF.
		BASIN: PATTERSON			
OCTOBER	240	225	6.75	1988	0.951
NOVEMBER	570	392	45.52	5838	.713
DECEMBER	1267	1142	10.97	7298	.937
JANUARY	1416	1622	-12.68	-18751	.916
FEBRUARY	1408	1479	-4.81	8731	.772
MARCH	1294	1640	-21.14	10000	.553
APRIL	2608	2776	-6.07	12378	.823
MAY	742	857	-13.44	-4532	.848
JUNE	368	445	-17.33	2362	.748
JULY	267	157	69.34	4190	.500
AUGUST	136	221	-38.35	-2055	.981
SEPTEMBER	202	265	-23.81	-1857	.790
WATER YEARS	872	931	-6.33	-18751	0.840
BEST FIT LINE:	A = 4.435	B = 0.888			
RMS = 1286	RATIO = 1.382				
		BASIN: LAUREL			
OCTOBER	139	75	84.99	2218	0.793
NOVEMBER	121	80	51.25	2282	.838
DECEMBER	580	552	5.07	3002	.843
JANUARY	514	515	-0.19	1773	.907
FEBRUARY	704	795	-11.43	-2381	.963
MARCH	564	648	-12.97	-1202	.916
APRIL	419	465	-9.93	1246	.959
MAY	295	273	7.97	1741	.862
JUNE	29	37	-21.41	185	.279
JULY	94	48	94.68	1066	.592
AUGUST	126	78	62.21	1021	.585
SEPTEMBER	42	34	21.73	512	.845
WATER YEARS	301	298	0.98	3002	0.914
BEST FIT LINE:	A = 0.738	B = 0.904			
RMS = 257	RATIO = 0.863				

TABLE XXIV

TOTAL AREA CATCHMENT MODEL FINAL CALIBRATION STATISTICS, COLLINS AND EDINBURG

MULTIYEAR STATISTICAL SUMMARY

MONTH	SIMULATED MEAN	OBSERVED MEAN	PERCENT BIAS	MAXIMUM ERROR	CORREL. COEFF.
		BASIN: COLLINS			
OCTOBER	444	375	18.44	9653	0.870
NOVEMBER	276	258	7.28	-1780	.850
DECEMBER	1488	1389	7.92	7674	.829
JANUARY	1693	1509	12.20	3796	.935
FEBRUARY	2015	2021	-0.29	-5119	.964
MARCH	1679	1805	-6.98	-4128	.917
APRIL	1166	1394	-16.36	-4993	.954
MAY	986	954	3.34	3525	.921
JUNE	265	220	20.53	1869	.628
JULY	228	224	1.95	981	.744
AUGUST	249	280	-10.83	225	.561
SEPTEMBER	209	176	18.68	1960	.931
WATER YEARS	888	878	1.06	9653	0.924
BEST FIT LINE:	A = 3.060	B = 0.868			
RMS = 645	RATIO = 0.734				
		BASIN: EDINBURG			
OCTOBER	274	260	5.68	2961	0.710
NOVEMBER	130	129	1.01	1545	.862
DECEMBER	1564	1355	15.36	10213	.912
JANUARY	2254	1991	13.21	-4313	.942
FEBRUARY	2009	2035	-1.31	2214	.962
MARCH	1765	2154	-18.04	-1849	.956
APRIL	1532	1890	-18.95	-7877	.954
MAY	1405	1238	13.42	4005	.955
JUNE	179	137	30.40	-923	.367
JULY	219	242	-0.80	953	.788
AUGUST	158	198	-19.96	-1284	.741
SEPTEMBER	227	196	15.95	1602	.817
WATER YEARS	974	982	-0.85	10213	0.932
BEST FIT LINE:	A = 3.456	B = 0.883			
RMS = 671	RATIO = 0.683				

TABLE XXV

TOTAL AREA CATCHMENT MODEL FINAL CALIBRATION STATISTICS, GLENMORA AND OBERLIN

MULTIYEAR STATISTICAL SUMMARY

MONTH	SIMULATED MEAN	OBSERVED MEAN	PERCENT BIAS	MAXIMUM ERROR	CORREL. COEFF.
BASIN: GLENMORA					
OCTOBER	275	120	128.33	3462	0.851
NOVEMBER	206	182	12.73	-6701	.352
DECEMBER	1366	1069	27.82	5638	.844
JANUARY	1006	1091	-7.55	-5731	.758
FEBRUARY	996	1263	-21.10	-31867	.790
MARCH	559	863	-35.21	-3476	.780
APRIL	672	855	-21.43	-12130	.810
MAY	464	549	-15.55	-3418	.879
JUNE	220	168	30.82	2577	.707
JULY	70	90	-21.86	631	.735
AUGUST	82	66	25.02	1332	.558
SEPTEMBER	95	58	64.13	2406	.523
WATER YEARS	500	528	-5.38	-31867	0.762
BEST FIT LINE:	A = 1.082 B = 0.980				
RMS = 919	RATIO = 1.741				
BASIN: OBERLIN					
OCTOBER	126	141	-11.05	-1541	0.847
NOVEMBER	259	248	4.48	-2803	.931
DECEMBER	1589	1341	18.53	4861	.846
JANUARY	1318	1308	0.73	3436	.945
FEBRUARY	1932	2101	-8.04	-8399	.968
MARCH	1336	1438	-7.14	-8735	.857
APRIL	1586	1698	-6.57	6427	.930
MAY	1105	1040	6.18	4579	.896
JUNE	261	218	19.46	913	.942
JULY	226	134	68.68	2985	.672
AUGUST	119	84	42.82	555	.567
SEPTEMBER	159	90	77.72	1059	.543
WATER YEARS	829	813	1.98	-8735	0.932
BEST FIT LINE:	A = 1.425 B = 0.920				
RMS = 664	RATIO = 0.816				

so derived). Therefore, several multi-zone calibration runs were made, this time adjusting parameters attempting to improve simulation while still retaining identical sets in each zone. The "best" set of these distributed input parameters will later serve as initial values for distributed input-distributed parameter calibration, and are listed as such in Tables XIV through XXI under columns Z1, Z2, Z3, for required basin zones. The parameter SSOUT, while noted in each zone, is actually a single add or withdrawal function, contributing to channel water after all components of flow are run through the time-delay histogram.

Tables XXVI through XXIX display distributed input model statistical results for the apparent best run. Comparing these mean daily flow statistics with those from lumped TA model simulation, one arrives at uncertain conclusions. Water year (WY) means generally are little changed, with perhaps three basins indicating some degeneration in simulation due to multi-zone modeling. WY Bias indicated three basins essentially unchanged, two worse and three somewhat better. WY Maximum Error statistic shows maybe a 50-50 split in simulation improvement. WY Correlation Coefficient: five basins essentially unchanged, one worse, three better. No significant change in the Best Fit Line for any watershed. For RMS, no real change for two basins, four better and two worse the score for remaining watersheds. Ratio also shows mixed results, leading one to at least conclude that there is no hard evidence of distributed input model superiority, nor is there evidence of significant simulation deterioration. Examination of the monthly statistics similarly reveals a near 50-50 split in lumped model versus distributed input model relative performance, with no evidence of seasonal preference, one mode of operation over the other.

TABLE XXVI

DISTRIBUTED INPUT MODEL FINAL CALIBRATION STATISTICS, FAYETTEVILLE AND IMBODEN

MULTIYEAR STATISTICAL SUMMARY

MONTH	SIMULATED MEAN	OBSERVED MEAN	PERCENT BIAS	MAXIMUM ERROR	CORREL. COEFF.
BASIN: FAYETTEVILLE					
OCTOBER	535	377	42.12	5121	0.790
NOVEMBER	814	685	18.80	3438	.888
DECEMBER	2068	1730	19.54	14939	.936
JANUARY	2164	2049	5.63	-6061	.947
FEBRUARY	2170	2346	-7.49	5500	.960
MARCH	2100	2333	-9.98	-4343	.961
APRIL	1947	2335	-16.62	-4702	.955
MAY	1745	2024	-13.78	-5146	.901
JUNE	627	676	-7.21	1644	.829
JULY	667	591	12.84	2420	.907
AUGUST	487	415	17.19	1821	.625
SEPTEMBER	444	361	22.81	2082	.593
WATER YEARS	1315	1332	-1.27	14939	0.927
BEST FIT LINE: A = 5.103 B = 0.877					
RMS = 829 RATIO = 0.627					
BASIN: IMBODEN					
OCTOBER	800	771	3.82	-1553	0.876
NOVEMBER	881	1061	-16.92	-2419	.957
DECEMBER	2116	2204	-3.99	-4916	.972
JANUARY	2182	2252	-3.13	3777	.989
FEBRUARY	1891	1962	-3.61	4704	.928
MARCH	1859	1961	-5.22	3413	.961
APRIL	2608	2506	4.06	7908	.937
MAY	1915	1917	-0.12	10934	.751
JUNE	1003	985	1.87	3188	.594
JULY	626	622	0.62	2817	.333
AUGUST	1170	703	66.36	20914	.953
SEPTEMBER	1081	749	44.45	4853	.875
WATER YEARS	1509	1472	2.52	20914	0.905
BEST FIT LINE: A = 7.825 B = 0.792					
RMS = 1105 RATIO = 0.751					

TABLE XXVII

DISTRIBUTED INPUT MODEL FINAL CALIBRATION STATISTICS, PATTERSON AND LAUREL

MULTIYEAR STATISTICAL SUMMARY

MONTH	SIMULATED MEAN	OBSERVED MEAN	PERCENT BIAS	MAXIMUM ERROR	CORREL. COEFF.
BASIN: PATTERSON					
OCTOBER	209	225	-6.97	1736	0.936
NOVEMBER	544	392	38.65	5489	.733
DECEMBER	1271	1142	11.29	8827	.944
JANUARY	1336	1622	-17.66	-17717	.935
FEBRUARY	1185	1479	-19.92	6953	.801
MARCH	1069	1641	-34.81	8610	.684
APRIL	2300	2776	-17.15	-9844	.854
MAY	707	857	-17.48	-5100	.827
JUNE	428	445	-3.72	3589	.771
JULY	280	157	78.21	4271	.679
AUGUST	131	221	-40.75	-2115	.976
SEPTEMBER	207	265	-21.70	3888	.758
WATER YEARS	802	931	-13.82	-17717	0.861
BEST FIT LINE:	A = 5.229	B = 0.930			
RMS = 1199	RATIO = 1.288				
BASIN: LAUREL					
OCTOBER	136	75	81.92	2174	0.823
NOVEMBER	116	80	45.43	1699	.878
DECEMBER	588	552	6.60	3454	.827
JANUARY	509	515	-1.10	1520	.918
FEBRUARY	707	795	-11.14	-3182	.960
MARCH	568	648	-12.31	-1035	.912
APRIL	415	465	-10.89	1450	.956
MAY	299	273	9.37	1690	.871
JUNE	30	37	-18.52	211	.301
JULY	101	48	109.39	1178	.670
AUGUST	132	78	70.24	1899	.553
SEPTEMBER	43	34	25.76	498	.831
WATER YEARS	302	298	1.34	3454	0.910
BEST FIT LINE:	A = 0.729	B = 0.900			
RMS = 262	RATIO = 0.881				

TABLE XXVIII

DISTRIBUTED INPUT MODEL FINAL CALIBRATION STATISTICS, COLLINS AND EDINBURG

MULTIYEAR STATISTICAL SUMMARY

MONTH	SIMULATED MEAN	OBSERVED MEAN	PERCENT BIAS	MAXIMUM ERROR	CORREL. COEFF.
BASIN: COLLINS					
OCTOBER	390	375	3.86	-4423	0.844
NOVEMBER	281	258	9.13	2044	.870
DECEMBER	1498	1389	8.65	6969	.845
JANUARY	1658	1509	9.84	4098	.936
FEBRUARY	2062	2021	2.03	-4991	.966
MARCH	1670	1805	-7.48	-4186	.911
APRIL	1183	1394	-15.15	4684	.950
MAY	926	954	-2.93	-3126	.921
JUNE	256	220	16.54	1506	.694
JULY	236	224	5.51	1084	.661
AUGUST	254	280	-9.25	2198	.537
SEPTEMBER	206	176	16.79	1130	.945
WATER YEARS	881	878	0.34	6969	0.931
BEST FIT LINE:	A = 3.113	B = 0.873			
RMS = 618	RATIO = 0.704				
BASIN: EDINBURG					
OCTOBER	279	260	7.30	2761	0.730
NOVEMBER	140	129	8.54	2584	.871
DECEMBER	1545	1355	14.00	10596	.910
JANUARY	2255	1991	13.26	4737	.945
FEBRUARY	1998	2035	-1.85	2757	.962
MARCH	1763	2154	-18.16	1770	.955
APRIL	1529	1890	-19.12	-4467	.971
MAY	1415	1238	14.28	4740	.955
JUNE	182	137	32.48	-933	.401
JULY	227	247	-6.46	1022	.811
AUGUST	169	198	-14.30	1908	.625
SEPTEMBER	227	196	16.00	1246	.824
WATER YEARS	975	982	-0.74	10596	0.937
BEST FIT LINE:	A = 3.423	B = 0.883			
RMS = 647	RATIO = 0.659				

TABLE XXIX

DISTRIBUTED INPUT MODEL FINAL CALIBRATION STATISTICS, GLENMORA AND OBERLIN

MULTIYEAR STATISTICAL SUMMARY

MONTH	SIMULATED MEAN	OBSERVED MEAN	PERCENT BIAS	MAXIMUM ERROR	CORREL. COEFF.
BASIN: GLENMORA					
OCTOBER	322	120	167.50	5225	0.881
NOVEMBER	243	182	33.28	-5575	.498
DECEMBER	1459	1069	36.53	5395	.853
JANUARY	1064	1091	-2.60	-5603	.769
FEBRUARY	1017	1263	-19.48	-32665	.772
MARCH	624	863	-27.71	-3198	.812
APRIL	696	855	-18.56	-12165	.804
MAY	504	549	-8.29	-3533	.856
JUNE	231	168	37.15	3670	.702
JULY	107	90	18.61	1882	.478
AUGUST	106	66	60.47	1259	.621
SEPTEMBER	153	58	163.17	3656	.651
WATER YEARS	543	528	2.73	-32665	0.743
BEST FIT LINE:	A = 1.025	B = 0.907			
RMS = 955	RATIO = 1.808				
BASIN: OBERLIN					
OCTOBER	125	141	-11.26	-1595	0.827
NOVEMBER	264	248	6.21	-3237	.915
DECEMBER	1592	1341	18.71	4746	.848
JANUARY	1313	1308	.38	3757	.938
FEBRUARY	1932	2101	-8.04	-8306	.969
MARCH	1336	1438	-7.11	-8732	.856
APRIL	1586	1698	-6.57	6330	.930
MAY	1107	1040	6.38	4356	.892
JUNE	262	218	19.96	923	.935
JULY	227	134	69.57	2767	.663
AUGUST	123	84	46.76	565	.586
SEPTEMBER	161	90	78.99	1145	.541
WATER YEARS	830	813	2.09	-8732	0.931
BEST FIT LINE:	A = 1.415	B = 0.919			
RMS = 665	RATIO = 0.818				

If the multiyear statistical summaries failed to suggest evidence of clear distributed model superiority, a visual examination of the plotted hydrographs, simulated versus observed, did indicate an improvement in selected storm reconstitution during periods when variable rainfall was most likely a problem. Armed with this satisfaction, it was decided to next adjust individual zone parameters to better reflect subbasin hydrology, and hopefully improve overall simulation through such a technique.

Distributed Input - Distributed Parameters

The parameters established so far would be classed by the hydrologic community as "lumped," in that a given parameter value represents, in truth, the possible average value across the basin for which calibration was performed. It is likely, of course, that there is some range of value for most parameters, and the multi-zone model is structured so as to allow this to be taken into account in at least a crude fashion. One familiar with the hydrology of a watershed can perhaps guess, if little else, as to the logical "gradation" in a parameter across a basin. Armstrong (47) reports on a procedure to derive initial parameter values from estimated engineering soil properties. While Soil Conservation Service (SCS) soil surveys were not used in this report as Armstrong suggests, soil maps and other published information pertaining to known hydrologic properties of the test basins were used to guide the gradation of parameters across zones. Most of all, "common sense hydrology" was used during trial-and-error adjustments to select individual zone parameters. For example, it would be reasonable for headwater zones to reflect shallower soils, low infiltration, high surface runoff, and lower baseflow contribution as compared to the higher storage and more alluvial plain type characteristics generally found in typical basin downstream zones. Effort was made to use zonal parameters such that the average of any given parameter across the zones computed out close to the lumped parameter value obtained from distributed input calibration. These rational but rudimentary parameter adjustments proved effective. The particular parameters utilized for distributed input-distributed mode calibration are as follows: UZTWM, UZFWM, LZTWM, LZFSM, LZFPM, PFREE, RESV, PCTIM, ADIMP. From this grouping, it is obvious that only those model parameters that are major factors in soil moisture storage or impervious area runoff generation were altered. Experience taught that it is difficult, if not impossible, to adjust the percolation curve directly and individually across the zones and improve simulation, as much as it might seem desirous to do so. However, since PBASE is a function of LZFSM and LZFPM, changing the latter two parameters does have the effect of shifting the lower end of the percolation curve up or down. For the most part, though, simulation was improved by changing the values of upper zone storage and runoff parameters, which had a noticeable effect on high flow reconstitution for many storms. The distributed parameter sets found to improve simulation the most are tabulated in Tables XIV through XXI under Final Value, Z1, Z1, Z3.

The multi-year statistical summaries for distributed input-distributed parameter calibration are presented in Tables XXX through XXXIII. Comparing WY distributed input-distributed parameter results with those obtained from distributed input simulation, the following is apparent: WY means are again mostly unchanged, with two basins

TABLE XXX

DISTRIBUTED INPUT-DISTRIBUTED PARAMETER MODEL FINAL CALIBRATION STATISTICS, FAYETTEVILLE AND IMBODEN

MULTIYEAR STATISTICAL SUMMARY

MONTH	SIMULATED MEAN	OBSERVED MEAN	PERCENT BIAS	MAXIMUM ERROR	CORREL. COEFF.
BASIN: FAYETTEVILLE					
OCTOBER	527	377	38.46	5099	0.699
NOVEMBER	817	685	19.27	3482	.881
DECEMBER	2090	1730	20.8	15131	.911
JANUARY	2183	2049	6.53	-5989	.953
FEBRUARY	2280	2346	-2.81	4277	.966
MARCH	2210	2333	-5.27	-4146	.984
APRIL	1852	2335	-20.68	-4437	.961
MAY	1830	2024	-9.58	-5100	.913
JUNE	638	676	-5.62	1702	.831
JULY	668	591	13.02	2310	.940
AUGUST	487	415	17.19	1830	.621
SEPTEMBER	440	361	17.34	2079	.498
WATER YEARS	1320	1332	-0.90	15131	0.935
BEST FIT LINE:	A = 4.931	B = 0.911			
RMS = 818	RATIO = 0.614				
BASIN: IMBODEN					
OCTOBER	806	771	4.54	-1662	0.856
NOVEMBER	889	1061	-16.21	-2410	.941
DECEMBER	2173	2204	-1.41	-4930	.970
JANUARY	2157	2252	-4.22	3812	.971
FEBRUARY	1899	1962	-3.21	4710	.929
MARCH	1950	1961	-.56	3185	.964
APRIL	2533	2506	1.08	7487	.953
MAY	1915	1917	- .012	10836	.799
JUNE	999	985	1.42	3312	.624
JULY	631	622	.643	2702	.310
AUGUST	1170	703	66.36	21050	.954
SEPTEMBER	1002	749	33.77	4777	.875
WATER YEARS	1507	1472	2.37	21050	0.918
BEST FIT LINE:	A = 7.122	B = 0.790			
RMS = 1100	RATIO = 0.747				

TABLE XXXI

DISTRIBUTED INPUT-DISTRIBUTED PARAMETER MODEL FINAL CALIBRATION STATISTICS, PATTERSON AND LAUREL

MULTIYEAR STATISTICAL SUMMARY

MONTH	SIMULATED MEAN	OBSERVED MEAN	PERCENT BIAS	MAXIMUM ERROR	CORREL. COEFF.
BASIN: PATTERSON					
OCTOBER	212	225	-5.78	1738	0.938
NOVEMBER	509	392	29.85	5499	.742
DECEMBER	1302	1142	14.01	8811	.918
JANUARY	1330	1622	-18.00	-17596	.930
FEBRUARY	1222	1479	-17.38	6951	.808
MARCH	1264	1640	-22.92	8600	.672
APRIL	2410	2776	-13.18	-9732	.881
MAY	709	857	-17.27	-4998	.836
JUNE	428	445	-3.72	3581	.769
JULY	289	157	84.07	4185	.691
AUGUST	129	221	-41.63	-2119	.954
SEPTEMBER	210	265	-20.75	3829	.761
WATER YEARS	825	931	-11.38	-9732	0.877
BEST FIT LINE:	A = 5.112	B = 0.933			
RMS = 1183	RATIO = 1.270				
BASIN: LAUREL					
OCTOBER	109	75	45.33	2190	0.819
NOVEMBER	113	80	41.25	1683	.877
DECEMBER	588	552	6.60	3450	.827
JANUARY	501	515	-2.72	1528	.922
FEBRUARY	712	795	-10.44	-3182	.968
MARCH	571	648	-11.88	-1012	.919
APRIL	429	465	-7.74	1425	.958
MAY	291	273	6.59	1699	.891
JUNE	31	37	-16.21	213	.299
JULY	102	48	112.50	1179	.681
AUGUST	130	78	66.66	1920	.554
SEPTEMBER	40	34	17.65	491	.810
WATER YEARS	301	298	1.00	3450	0.924
BEST FIT LINE:	A = .700	B = .893			
RMS = 251	RATIO = 0.842				

TABLE XXXII

DISTRIBUTED INPUT-DISTRIBUTED PARAMETER MODEL FINAL CALIBRATION STATISTICS, COLLINS AND EDINBURG

MULTIYEAR STATISTICAL SUMMARY

MONTH	SIMULATED MEAN	OBSERVED MEAN	PERCENT BIAS	MAXIMUM ERROR	CORREL. COEFF.
BASIN: COLLINS					
OCTOBER	387	375	3.20	-4419	0.822
NOVEMBER	280	258	8.52	2039	.871
DECEMBER	1492	1389	7.41	6979	.848
JANUARY	1668	1509	10.53	4090	.942
FEBRUARY	2058	2021	1.83	-4879	.971
MARCH	1699	1805	-5.87	-4200	.951
APRIL	1202	1394	-13.77	4682	.922
MAY	920	954	-3.56	-3111	.911
JUNE	258	220	17.27	1501	.691
JULY	235	224	4.91	1081	.660
AUGUST	258	280	-7.86	2199	.538
SEPTEMBER	209	176	18.75	1125	.946
WATER YEARS	885	878	0.79	6979	0.942
BEST FIT LINE:	A = 3.218	B = .878			
RMS = 612	RATIO = 0.697				
BASIN: EDINBURG					
OCTOBER	227	260	6.54	2755	0.740
NOVEMBER	140	129	8.54	2581	.873
DECEMBER	1540	1355	13.65	10602	.908
JANUARY	2251	1991	13.05	4741	.951
FEBRUARY	1979	2035	-2.75	2646	.960
MARCH	1766	2154	-18.01	1759	.961
APRIL	1541	1890	-18.46	-4460	.973
MAY	1411	1238	13.97	4801	.952
JUNE	189	137	37.95	-931	.408
JULY	225	242	-7.02	1030	.831
AUGUST	170	198	-14.14	1906	.600
SEPTEMBER	226	196	15.31	1245	.820
WATER YEARS	979	982	-0.30	10602	0.939
BEST FIT LINE:	A = 3.510	B = 0.880			
RMS = 649	RATIO = .0.660				

TABLE XXXIII

DISTRIBUTED INPUT-DISTRIBUTED PARAMETER MODEL FINAL CALIBRATION STATISTICS, GLENMORA AND OBERLIN

MULTIYEAR STATISTICAL SUMMARY

MONTH	SIMULATED MEAN	OBSERVED MEAN	PERCENT BIAS	MAXIMUM ERROR	CORREL. COEFF.
BASIN: GLENMORA					
OCTOBER	303	120	152.50	5199	0.879
NOVEMBER	238	182	30.77	-5580	.478
DECEMBER	1451	1069	35.73	5412	.854
JANUARY	1060	1091	-2.84	-5605	.768
FEBRUARY	1012	1263	-19.87	-31330	.800
MARCH	681	863	-21.08	-2848	.846
APRIL	669	855	-21.75	-12219	.785
MAY	510	549	-7.10	-3410	.871
JUNE	230	168	36.90	3696	.703
JULY	109	90	21.11	1860	.481
AUGUST	108	66	63.63	1248	.643
SEPTEMBER	145	58	150.00	3615	.681
WATER YEARS	543	528	2.84	-31330	0.872
BEST FIT LINE:	A = 0.997	B = 0.913			
RMS = 941	RATIO = 1.782				
BASIN: OBERLIN					
OCTOBER	128	141	-9.22	-1610	0.822
NOVEMBER	263	248	6.04	-3239	.917
DECEMBER	1588	1341	18.50	4751	.849
JANUARY	1311	1308	.229	3699	.941
FEBRUARY	1943	2101	-7.52	-8109	.973
MARCH	1351	1438	-6.05	-8190	.859
APRIL	1599	1698	-5.83	6313	.941
MAY	1063	1040	2.21	4370	.888
JUNE	225	218	3.21	911	.930
JULY	138	134	2.98	2103	.660
AUGUST	125	84	48.81	568	.586
SEPTEMBER	160	90	77.78	1141	.540
WATER YEARS	826	813	1.59	-8190	0.929
BEST FIT LINE:	A = 1.212	B = .923			
RMS = 658	RATIO = 0.809				

indicating perhaps significant improvement in mean daily flow simulation due to multi-zone modeling. WY Bias indicates six basins improved, two somewhat worse. WY Maximum Error displays mixed results; WY Correlation Coefficient in all but two cases at least slightly better. There appears to be no significant change in the Best Fit Line for any watershed. RMS and Ratio were lowered for six basins, all of which at least indicates that perhaps a distributed input-distributed parameter model is a step in the right direction. But there, again, is no hard evidence of distributed model superiority, at least as can be discerned from mean daily flow statistics. It is interesting to note, however, that the results do indicate a trend toward improved simulation during spring months for most watersheds, a period of most prevalent and intense convective activity, which may be significant. Also a visual examination of the simulation hydrographs indicated the greatest improvement in storm reconstitution did occur for over-bank rises.

Distributed Model Evaluation

If mean daily flow statistics fail to prove the case for or against multi-zone modeling, one is forced to view different statistics tailored to single storm analysis. And since rises over the eight test watersheds exhibit cresting times generally less than three days, it is necessary to utilize instantaneous flow data (observations) to check against, as has been pointed out previously in this thesis.

Weighted Average Errors

Earlier in this chapter the weighted average filtering statistic was discussed in detail. Table XXXIV presents the results of such an

TABLE XXXIV

MULTI-ZONE MODEL PERFORMANCE RESULTS

BASIN	NO. UNIF. RISES	NO. NON UNIF.	% CHG. $\bar{e}_u$	% CHG. $\bar{e}_n$	% CHG. $\bar{T}_u$	% CHG. $\bar{T}_n$	% CHG. $\bar{V}_u$	% CHG. $\bar{V}_n$	% CHG. WY BIAS
DISTRIBUTED INPUT									
FAYETTEVILLE	8	19	-3	-29	-4	-36	-11	-16	-37
IMBODEN	6	8	+12	-2	+9	-8	+14	-2	+185
PATTERSON	10	9	-10	-3	+2	-18	+11	-6	+118
LAUREL	4	8	+8	-32	+2	-29	+9	-3	+33
COLLINS	11	5	-10	-38	-2	-31	-11	-14	-70
EDINBURG	8	8	-11	-21	-2	-22	+6	-9	-13
GLENMORA	8	6	+9	-30	-3	-27	-2	-13	-46
OBERLIN	4	9	+4	-12	0	-15	+3	-4	+6
TOTAL ALL BASINS (AVERAGE)	59	72	0	-20	0	-23	+2	-8	+22
DISTRIBUTED INPUT-DISTRIBUTED PARAMETERS									
FAYETTEVILLE	8	19	-3	-24	-11	-33	-14	-21	-56
IMBODEN	6	8	+13	0	+12	-7	+11	-7	+169
PATTERSON	10	9	-4	+2	+14	-17	+6	-19	+80
LAUREL	4	8	+4	-20	+9	-23	+2	-13	0
COLLINS	11	5	-3	-24	-2	-21	-6	-19	-30
EDINBURG	8	8	-5	-23	-9	-16	-3	-18	-63
GLENMORA	8	6	+12	-19	-3	-24	+1	-20	-46
OBERLIN	4	9	+8	-11	-6	-9	0	-9	-19
TOTAL ALL BASINS (AVERAGE)	59	72	+3	-15	+1	-19	0	-16	+4

\- Weighted Error Reduction + Weighted Error Increase analysis. For the purpose of indicating the type of rain patterns that prevail over each test basin, a breakdown of the number of non-uniform and uniform storm generated rises is included. If the standard deviation of MZP was less than ten percent of the MBP, the storm was classified as uniform. It is clear from the table that Patterson, Collins, and Glenmora experience a majority of relatively uniform storms, whereas a basin like Fayetteville is exposed to mostly non-uniform rainfall patterns. All multi-zone model performance results (Table XXXIV) are relative to the TA lumped model. A reduction in weighted average error for multi-zone simulation signifies improvement in simulation performance over the lumped model, as measured by the given statistics. As for example, a -13 percent change in peak error for all non-uniform storm rises, $\bar{e}_n$, when running the distributed input model, denotes a 13 percent reduction in peak flow error. In other words, the distributed input model improved the reconstitution of storm peak flows by 13 percent. A $\bar{T}_u$ value of +25 percent change for distributed input-distributed parameter mode simulation signifies an increase in peak timing error by 25 percent over that generated by the lumped model for uniform storm type rises. A $\bar{V}_n$ value of +38 percent change for, say, distributed input model simulation denotes that non-uniform storm rise volume error increased by 38 percent when operating in distributed input mode. Since WY Bias is an excellent measure of low flow model performance, as explained earlier in this chapter, the statistic is included as part of multi-zone model evaluation. A WY Bias change of, for example, -10 percent indicates a reduction in the bias statistic of 10 percent when operating in one of the multi-zone modes. The percent change in WY Bias, total area model (TA) versus multi-zone model

(MZ), can be computed from the relationship $\left((\text{MZ Bias} - \text{TA BIAS})/\text{TA Bias}\right) \cdot 100$, where Bias = $\left| \text{SMDQ} - \text{OMDQ} \right|$ for all water years. In a similar manner, the percent change in weighted error was determined. Regardless of the error statistic used in computing change due to distributed model simulation, the percentage values were rounded so as to eliminate fractional parts which were thought unnecessary.

The weighted average error tabulations for 131 rises in Table XXXIV allow considerable insight into multi-zone model simulation changes not evident from prior mean daily flow statistics. Distributed-input model error performance average for all watersheds may be evaluated thus: peak flow error unchanged for uniform storm rises, reduced by 20 percent for non-uniform storm rises; peak timing error for uniform storms no change, reduced by 23 percent for non-uniform storm rises; runoff volume error for uniform storms increased by only 2 percent, reduced by 8 percent for non-uniform storms. WY Bias, unfortunately, increased by 22 percent. However, that is due mostly to low flow degeneration at Imboden and Patterson, which are the only basins modeled with three zones (all other watersheds were broken down into two zones). This could be significant, as perhaps the number of zones is a factor here.

Distributed input-distributed parameter model performance may similarly be evaluated. For uniform storm generated rises, peak error increased by 3 percent, and reduced by 15 percent for non-uniform storms; timing error increased by only 1 percent for uniform storms, reduced by 19 percent for non-uniform events; runoff volume error for uniform storms, no change, and reduced by 18 percent for the non-uniform events. WY Bias increased a slight 4 percent, again due mostly to the three-zone watershed bias. Comparing, now, distributed input-distributed parameter (DI-DP) model basin average performance with that of the distributed input (DI) version, the following is apparent: the DI-DP model will slightly increase uniform storm rise peak error, whereas the DI version averages a zero change in error; the DI-DP model will reduce peak error for non-uniform storms, but not as much as the DI version; neither the DI-DP or DI models offer reduction in the timing error for uniform storms, though the DI version does improve the non-uniform storm timing DI-DP model; neither model offers much change in volume error for uniform storms, but the DI-DP model will sharply reduce non-uniform storm volume errors over that achieved by the DI version. Finally, the DI-DP model does not generate nearly as much low flow simulation error as does the DI version, though the issue is clouded due to low water simulation problems possibly caused by the three-zone configuration used to model Imboden and Patterson. It is possible that DI-DP modeling of the run-off peaks, both flow and timing, could be improved substantially by changing the time-delay histogram and reconfiguring the zones. All statistics considered, it seems that there is somewhat a trade-off involved in synthesizing streamflow with a multi-zone simulation technique: the DI version appears to do better reconstituting peaks, whereas the DI-DP model more closely simulates runoff volumes throughout the range of flows. Perhaps the latter indicates a physically more realistic accounting of soil moisture, a product of the distributed parameter feature. It should be noted that the average error tabulations (total for all basins) could instead be presented as weighted averages, the weights being number of uniform or non-uniform storms over each watershed. However, the results differ little from the simple arithmetic average computed, and would not affect the conclusions.

Single Storm Analysis

Having gained insight into the true performance characteristics of a multi-zone simulation model through the use of a filtering statistic, attention was next turned to plotting the individual storm errors. The error reduction, no weights considered as discussed earlier in this chapter, is presented in the form of percent improvement, multi-zone model over TA lumped model. A negative value, then denotes percent increase in error, or in other words, a decrease in multi-zone performance. Plots of storm error versus the associated storm rainfall variability (standard deviation of MZP) are presented in Figures 21 through 26, and offer a striking view of distributed model behavior. It should be recognized that a small standard deviation (σ) is probably associated with a small (low rainfall) storm, though this does not have to be. However, a large standard deviation must be associated with a large (heavy rainfall) storm. Also, since the RMS value is used frequently to measure model simulation performance during calibration, one must bear in mind that the statistic favors large events, resulting in parameters more tuned to high flows. The final basin fit, then, is perhaps not the best obtainable for lesser storms, and is indicated in Figures 21 through 26 by the rather large number of events displaying simulation degeneration below one-half inch σ values. As would be expected, most storms compute a variability of MZP less than one inch, leaving only 23 storms above 1.0 inch, six about 2.0 inches, and one above 3.0 inches. The 131 rises selected for single storm error

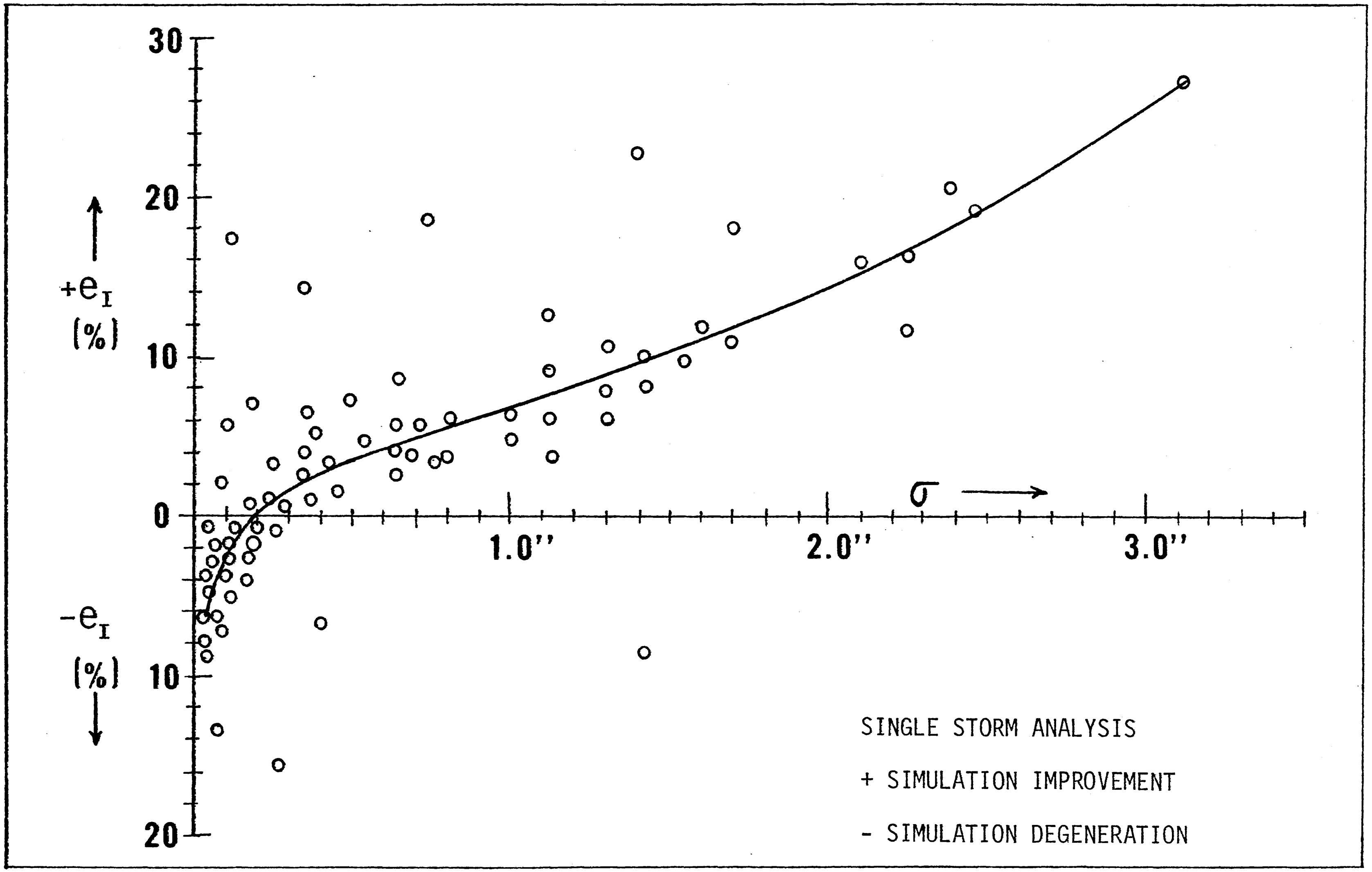


Figure 21. Multi-Zone Model, Distributed Input Peak Flow Storm Errors, All Basins

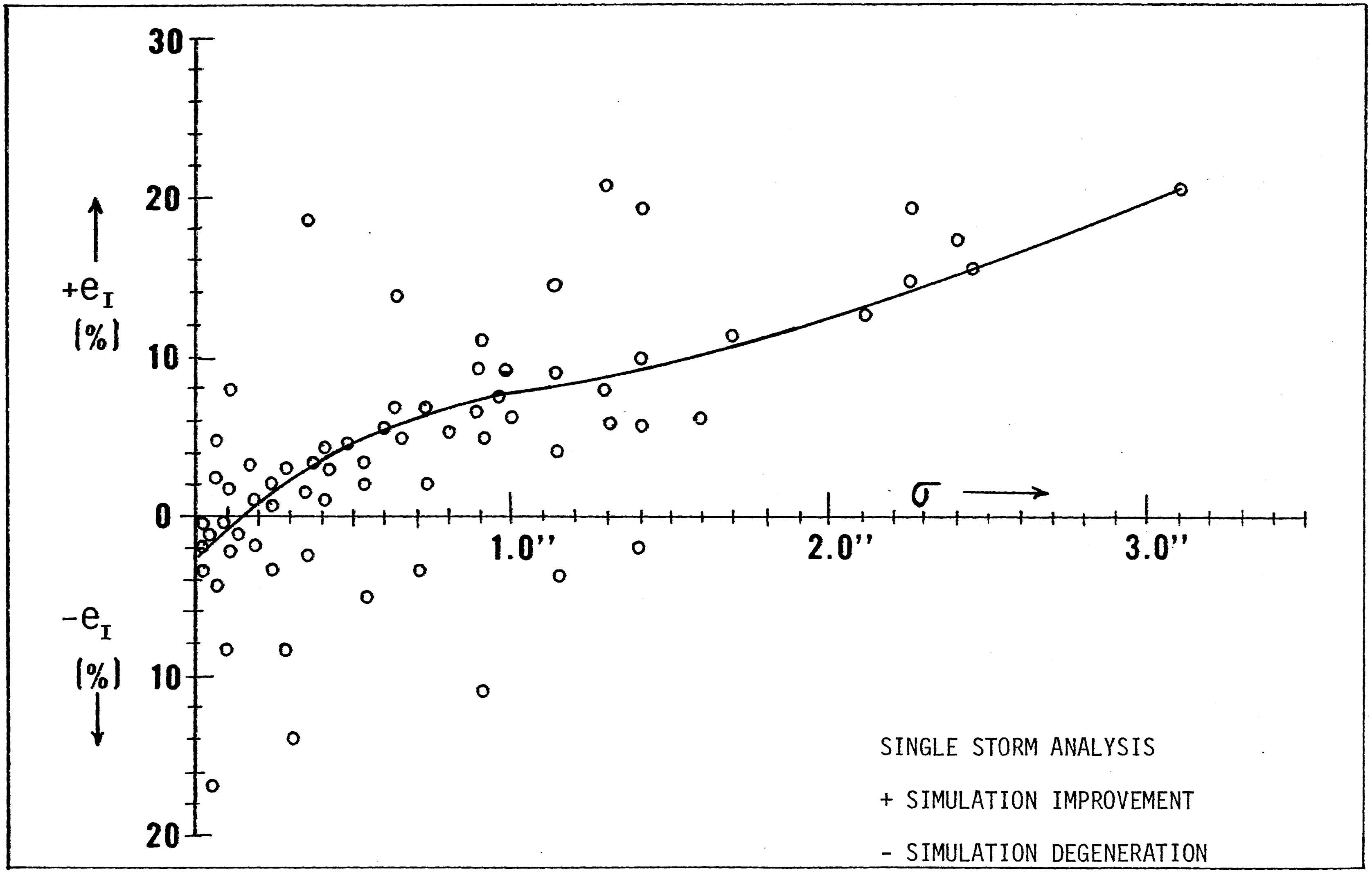


Figure 22. Multi-Zone Model, Distributed Input-Distributed Parameters Peak Flow Storm Errors, All Basins

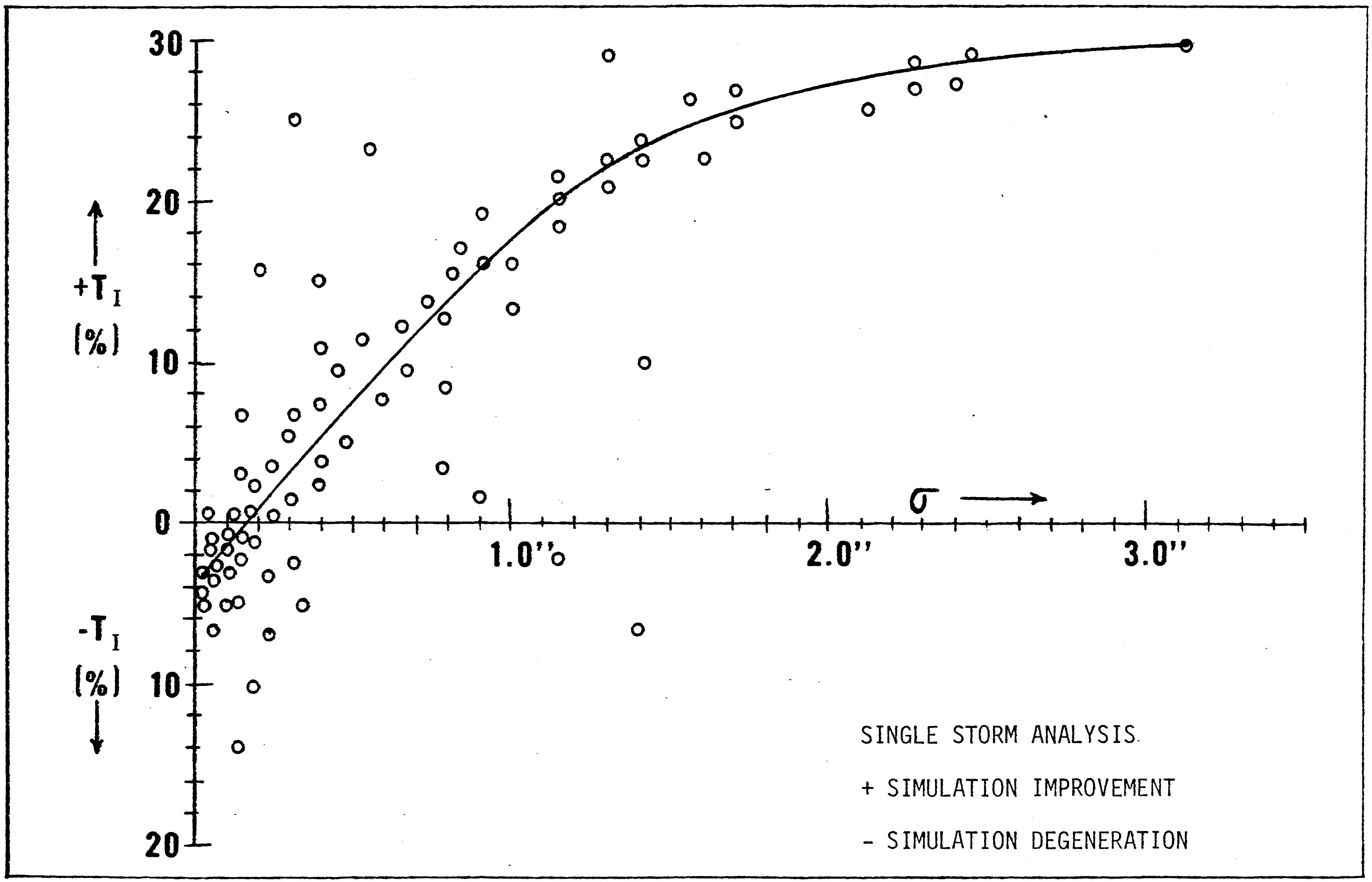


Figure 23. Multi-Zone Model, Distributed Input Timing Errors, All Basins

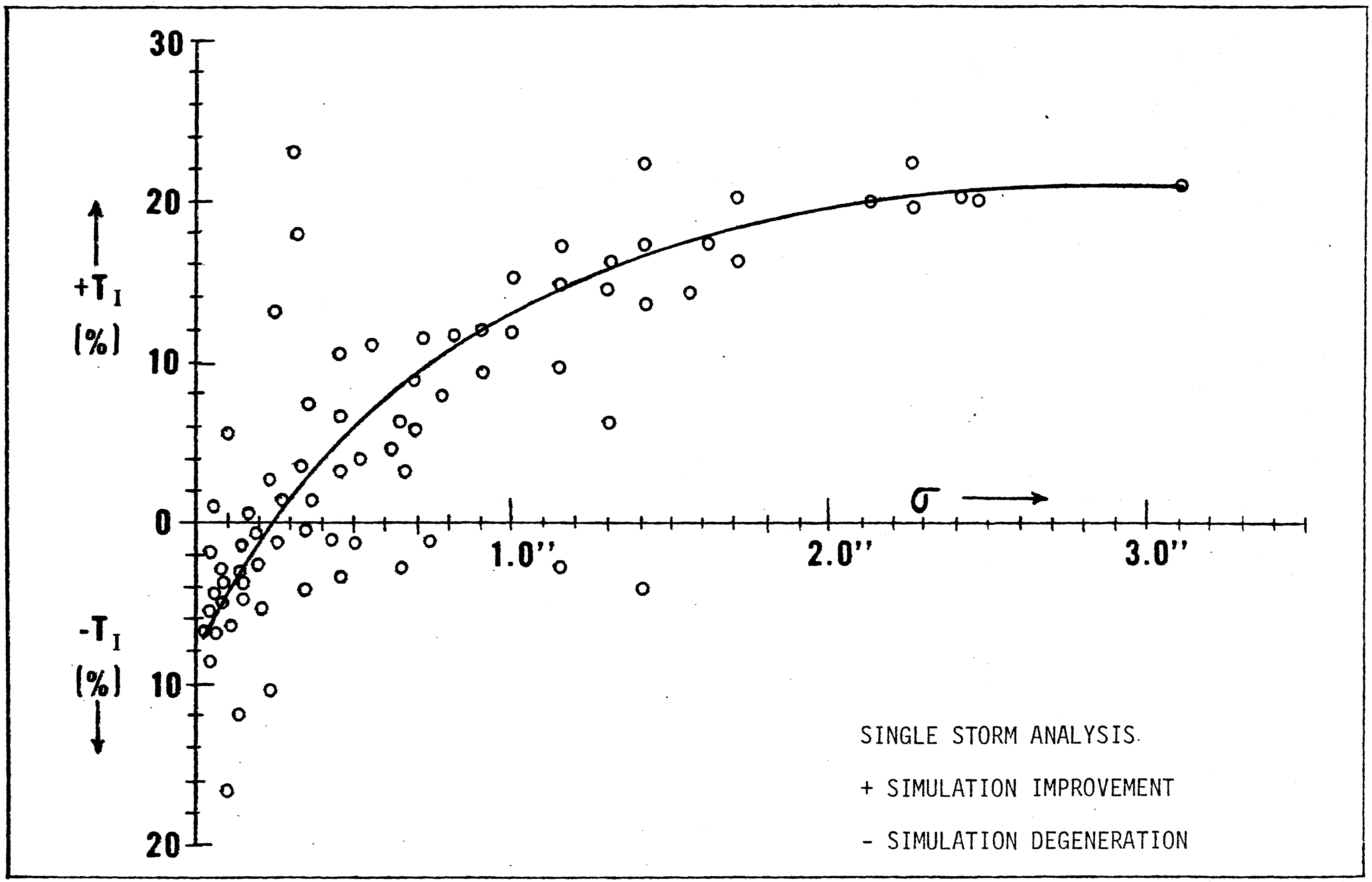


Figure 24. Multi-Zone Model, Distributed Input-Distributed Parameters Timing Errors, All Basins

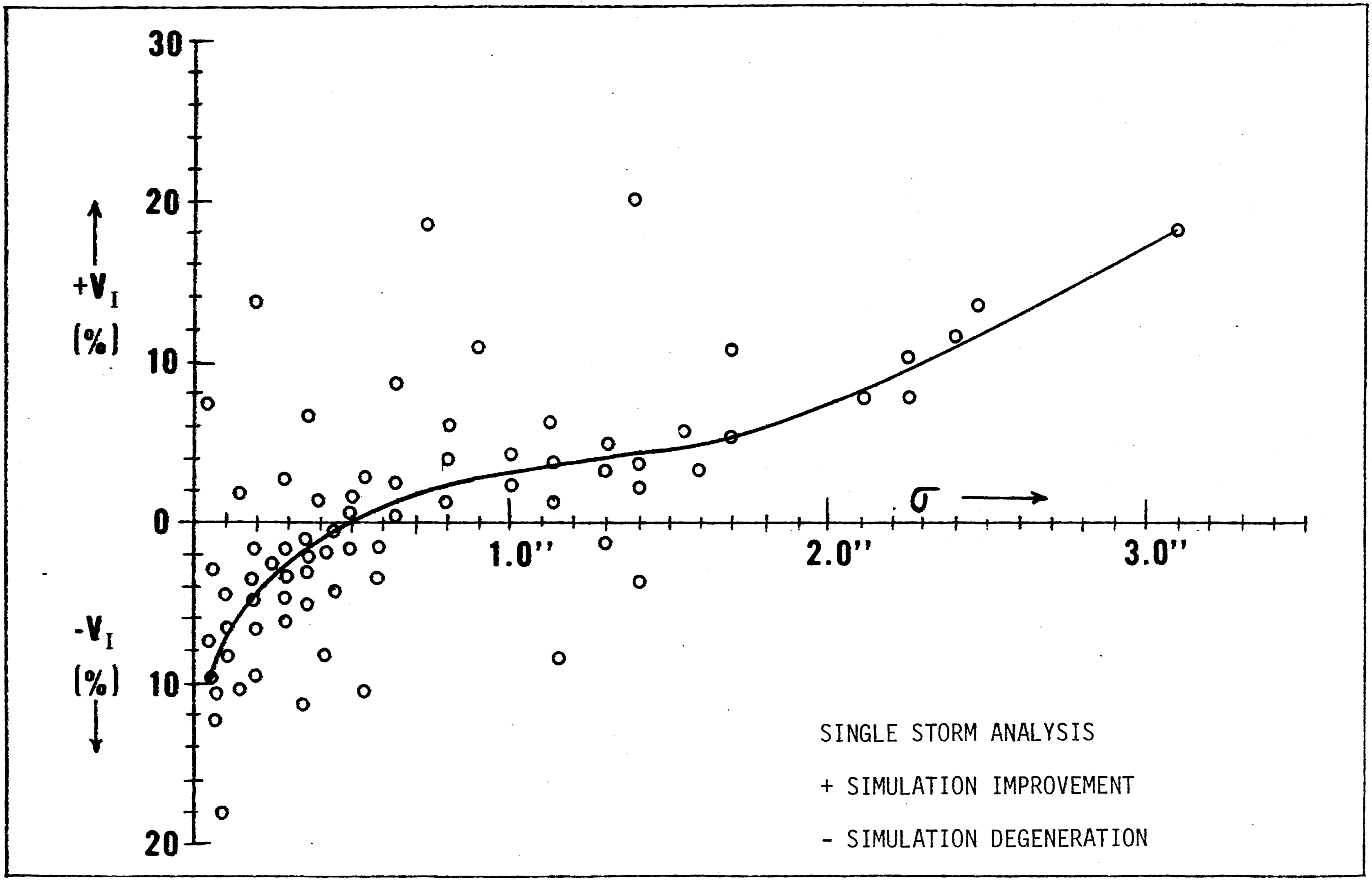


Figure 25. Multi-Zone Model, Distributed Input Storm Volume Errors, All Basins

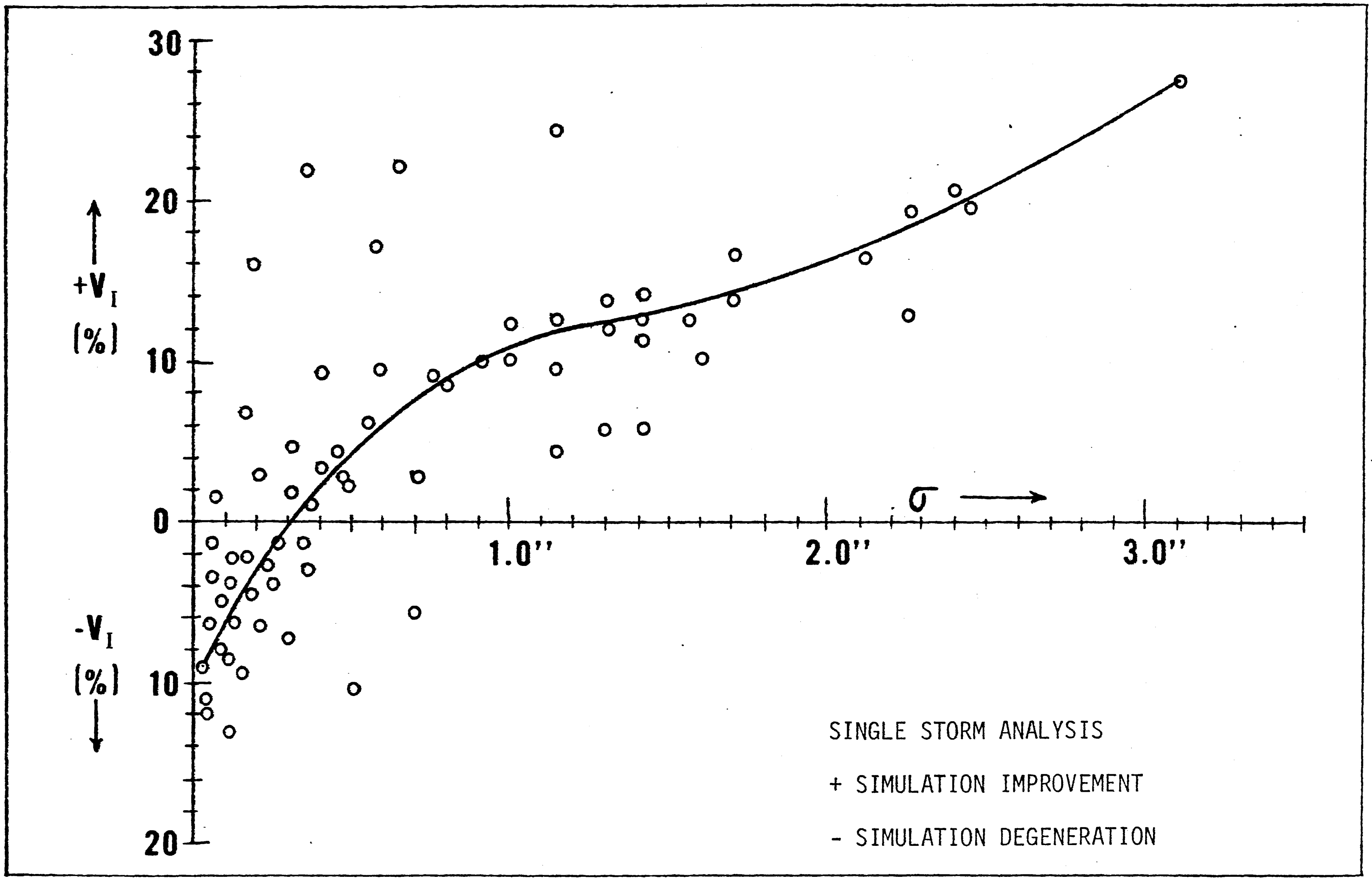


Figure 26. Multi-Zone Model, Distributed Input-Distributed Parameters Storm Volume Errors, All Basins

analysis compute a MBP (storm total) averaging near 2.0 inches. When viewing the graphs, it is worthwhile to consider a "threshold" value of σ, above which it is evident the greatest improvement in simulation may be obtained using a distributed hydrologic model. The best fit curve for the data, drawn on all charts, represents a "hand engineering" fit to the plotted points. A statistical fit could have been obtained using standard regression techniques, but was rejected since such procedures can produce a curve that is statistically optimum for small sample sizes, but hydrologically unreasonable. Below σ values of 1.0 inch, not all storm errors are plotted, as to include every one would clutter the drawing unnecessarily. Those plots omitted are concentrated close to the lower end of the curve.

Figure 21 displays percent improvement in storm peak flow simulation achieved by the DI model. It is clear that simulation degeneration predominates for storm σ values less than 0.2 inches. Above a threshold of σ = 0.2 inches, significant improvement in peak flow simulation is obtained, and above σ = 2.5 inches, the DI model consistently improves the peaks. Figure 22 indicates much the same thing for the DI-DP model, but the degree of improvement over the lumped model is not as great. There may be less degeneration in peak flow simulation below σ = 0.2, and a threshold σ of 1.0 again seems reasonable, but the percent improvement above 2.5 inches is below that of the DI model.

Looking now at percent improvement in timing, Figure 23 clearly shows the advantage of a DI model. Above σ = 0.2, improvement is proportional to the increase in σ, with a threshold of 0.5 inches most reasonable. From 1.5 to 3.0 inches, the percent improvement by the DI model over its lumped counterpart remains fairly constant. Figure 24 displays timing improvement for the DI-DP model, and it is clear that again a threshold of 0.2 inches is reasonable, but above 1.5 inches variability the percent improvement over lumped model remains nearly constant, reaching a maximum value on the order of 20 percent.

Figure 25 indicates that, for the DI model, most storm volume degeneration takes place below σ values of 0.5 inches. Above a threshold of 1.5 inches, substantial volume improvement takes place up to a maximum of 18 percent. However, the DI-DP model in Figure 26 indicates volume simulation degeneration mainly below 0.3 inches, which also appears to be a reasonable threshold. The leveling off in the 12 to 14 percent range may or may not exist, as it cannot be explained hydrologically, but regardless, the volume improvement above 14 percent is substantial. The DI-DP model clearly indicates a capability of improving storm runoff volumes more than the DI version.

Figures 27 through 29 are sample model output hydrographs. The simulation program generates observed (+) and simulated (*) mean daily flow (CFSD) hydrographs for each water year, plus instantaneous (CFS) flow plots for selected storm rises. Such displays are frequently useful in comparing model-to-model performance as well as indicating the match between observed and simulated flows.

Precipitation Gage Network

The evaluation of any hydrologic model requires representative rainfall data. A valid question in that regard would be: "How many rain gages are required in an area so that reliable mean areal precipitation can be computed?" For not only must the rainfall measurements be accurate, but sufficient reports available to give a reliable

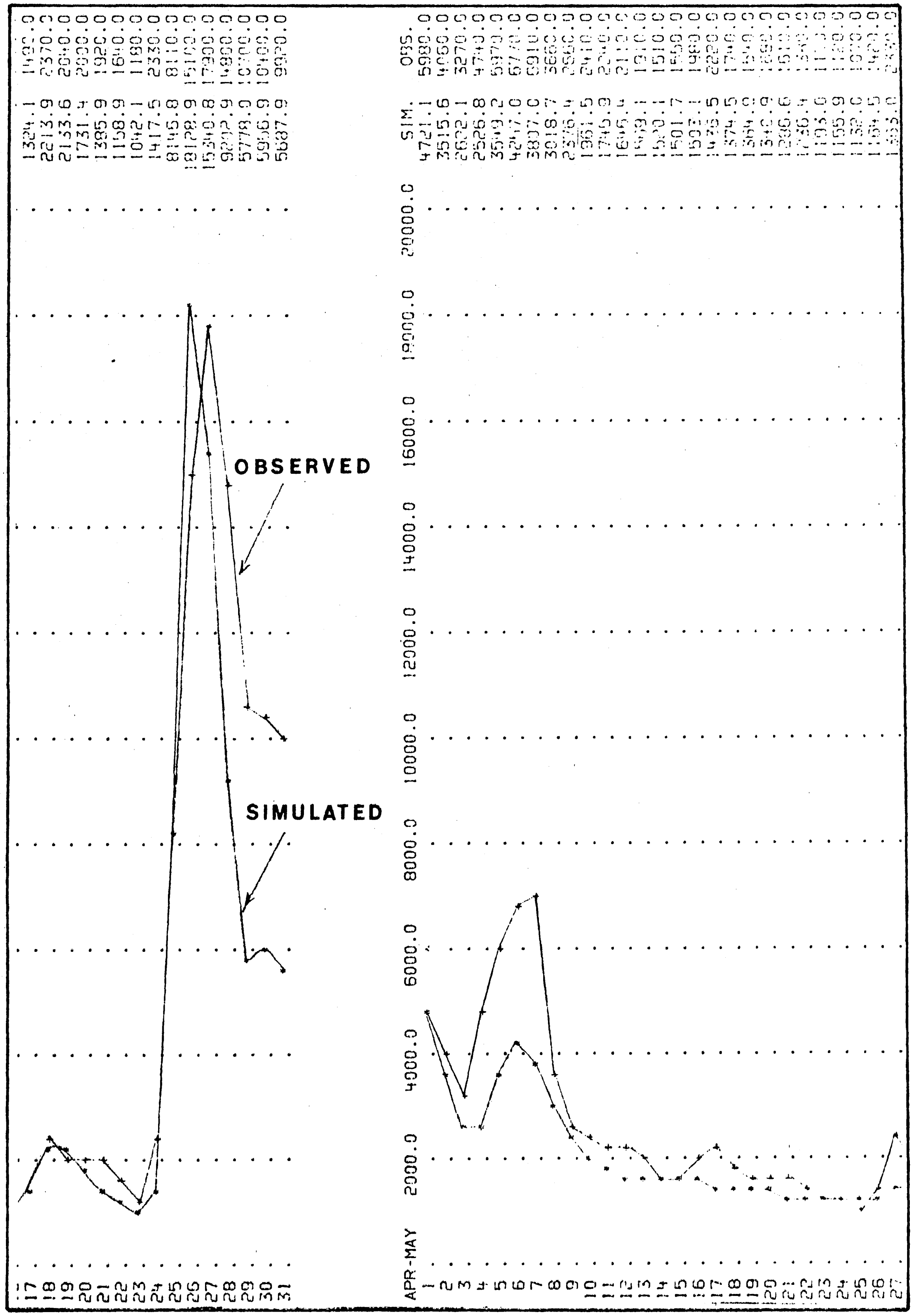
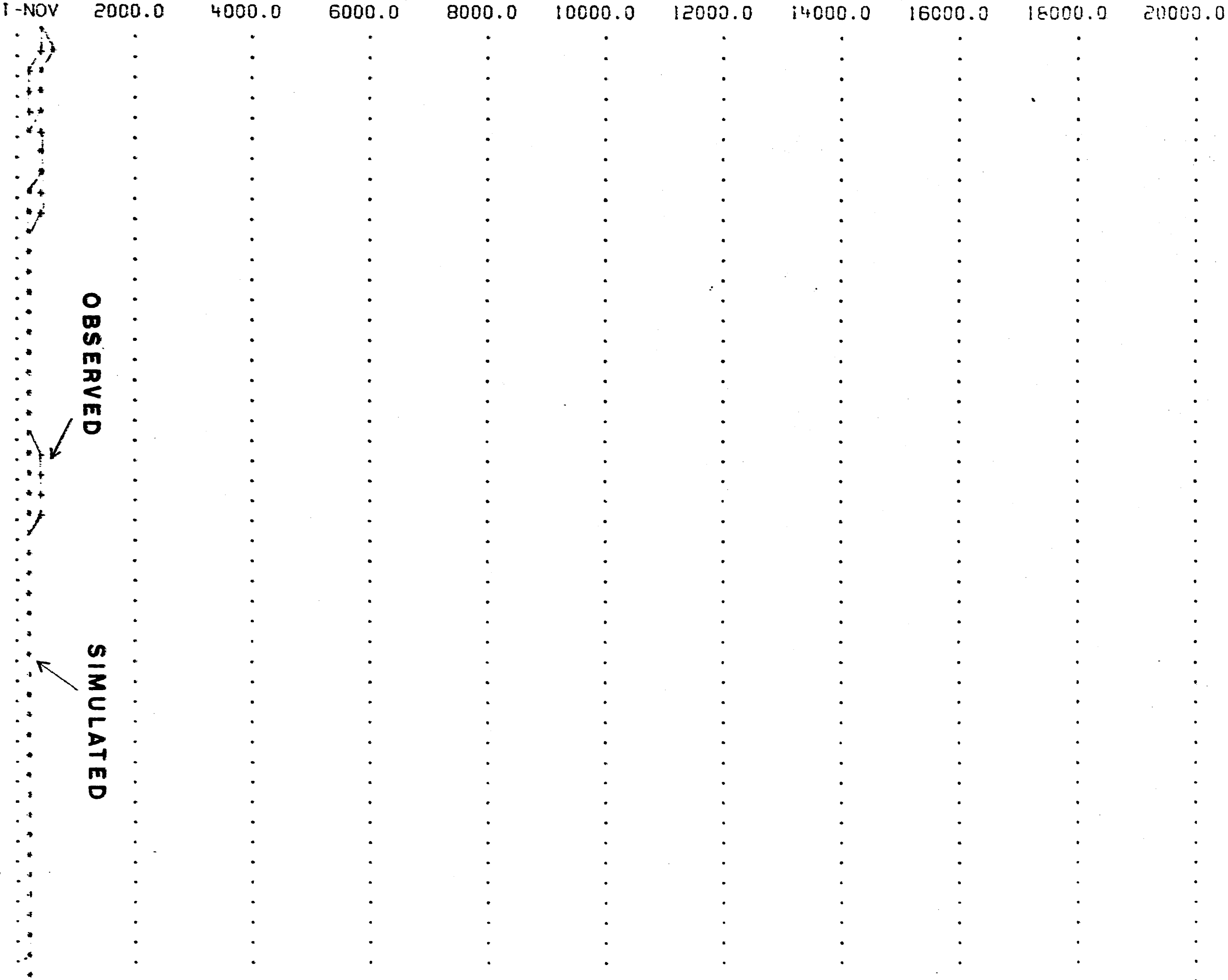


Figure 27. Storm Mean Daily Flow Hydrograph

MEAN DAILY FLOW PLOT FAYETTEVILLE, TN WATER YEAR 1966 *=SIMULATED +=OBSERVED UNITS-CFSD



OCT-NOV	SIM.	OBS.
1	499.3	302.0
2	621.7	331.0
3	492.4	300.0
4	380.5	297.0
5	318.6	289.0
6	291.6	349.0
7	338.0	446.0
8	315.7	448.0
9	287.3	403.0
10	269.0	322.0
11	257.5	282.0
12	249.2	277.0
13	245.0	275.0
14	241.5	273.0
15	233.3	271.0
16	230.6	269.0
17	226.0	269.0
18	221.3	266.0
19	222.8	264.0
20	240.4	266.0
21	235.0	284.0
22	285.3	302.0
23	267.0	305.0
24	237.5	319.0
25	223.6	302.0
26	217.7	273.0
27	213.9	269.0
28	210.8	269.0
29	206.5	266.0
30	202.4	264.0
31	200.3	266.0
1	195.5	265.0
2	191.5	266.0
3	191.0	264.0
4	195.0	266.0
5	203.3	260.0
6	204.2	269.0
7	204.0	269.0
8	208.1	269.0
9	203.6	273.0
10	203.8	275.0
11	200.4	271.0
12	195.9	247.0
13	208.3	244.0
14	195.9	242.0
15	195.1	235.0
16	192.1	233.0
17	187.2	231.0

Figure 28. Low Water Mean Daily Flow Hydrograph

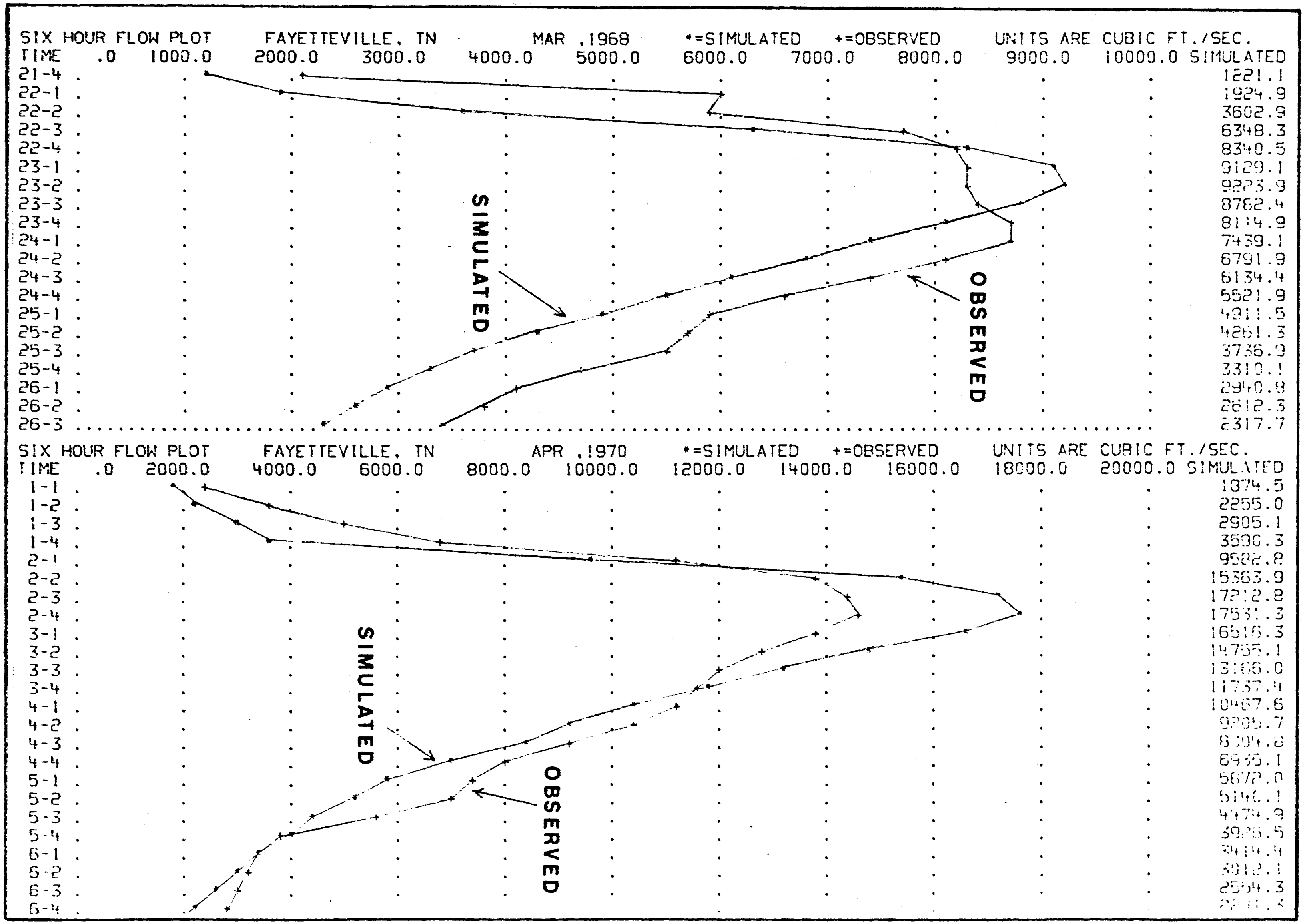


Figure 29. Instantaneous Flow Storm Hydrographs

estimate of the areal distribution of precipitation. Unless one is satisfied that the model is, in fact, utilizing areal means of reasonable accuracy, the calibration is difficult, if not impossible, and the research results clouded. Collinge and Jamieson (48), addressing the precipitation gage network design problem in 1968, state that historically, little attention has been given to the subject and that lack of such information is a severe handicap. Nicks (49) contends that if the existing network of rain gages were installed with a uniform spacing, fewer gages would give better results. Sharp (50) reported only a small difference of average rainfall amounts between 39 gages and 10 gages. However, the area used in his study was a mere 26 mi^2. Guest (51) computed the correlation of rainfall as a function of distance between stations for the USDA Blacklands network close to Riesel, Texas, and found that correlation between daily rainfall at two stations decreased monotonically for a distance of about 17 mi; at that distance, it either increased again or became stationary. Watt (52) reports that in a tropical area of 66 mi^2, one gage indicated rainfall on 47 percent of the days and that with 21 gages, the rain days increased to 58 percent. The amounts were not indicated.

Alvarez and Henry (53) studied ten rain gage networks over the world with continuous records relating observed daily, monthly, and mean monthly rainfall to rain gage density. Among other things, they conclude that for areas in South Central Texas the absolute error in rainfall nears 60 percent at a distance of 17 to 18 miles between gages, or at a density of approximately one gage per 270 mi^2. There are no published studies relating hydrologic model performance to input rainfall areal means of varying accuracy. If one includes all rain gages in the immediate periphery of the basin, the eight watersheds studied in this report have an average rain gage density on the order of one gage per 100 mi^2 at best. Spacing of rain gages is far from uniform, though always there is at least a sufficient distribution of gages so as to allow not only (hopefully) a resasonable estimate of MBP, but also an estimate of upstream and downstream concentrations. There is no evidence, then, from reports in the literature or from the calibration of the test basins (which is generally good) to allow contention that there is insufficient data over the eight watersheds to support multi-zone model research, though all would agree the network is not optimum. The average diameter of a typical one- to three-inch rain storm over the southeastern United States is probably on the order of 15 miles, which should be adequately sampled by the rain gage network existing over most of the research catchments, in this author's opinion.

However, there still remains a question as to what extent the different networks over each catchment might influence multi-zone model performance. In other words, could it be that among the eight basins tested herein the distributed model performed more according to rain gage network than according to model characteristics? What is needed to approach the question with an intelligent answer is some measure of both the number of rain gages and gage location relative to the basin. Sittner (23) suggests a basin rain gage index (RGI), each term of which may take on values from zero to ten that is a function of: a) rain gage density in relation to the random variability of precipitation (term I1), b) gage density in relation to the number of zones (term I2), and c) distribution of gages as measured by station weights (term I3). Then RGI = (I1 + I2 + I3)/3. It can be shown (derivation omitted), that

$$RGI = 13.33D + 0.22N + 3.33 \cdot \left[\frac{\left(\frac{N - 1}{N^2 + N}\right)^{\frac{1}{2}} - \sigma}{\left(\frac{N - 1}{N^2 - N}\right)^{\frac{1}{2}}} \right]$$

where

D = rain gage density

N = number of gages

σ = standard deviation of station weights

The larger the value of RGI, the better the network, with RGI computing a possible value up to ten. Based on this formula, the RGI for the test watersheds compute as: Fayetteville = 3.70, Imboden - 4.55, Patterson = 4.91, Laurel = 3.93, Collins = 4.58, Edinburg = 6.67, Glenmora = 3.79, Oberlin = 5.25. It is clear that there is not a great difference between these RGI values. Hence, one has no alternative but to conclude that, as measured by the RGI, the individual rain gage networks were not a factor, relative to each other, in distributed model versus lumped model simulation.

CHAPTER VII

CONCLUSIONS

From the multi-zone watershed modeling results presented herein, the following conclusions can be drawn:

1. It is possible to calibrate a distributed input or a distributed input-distributed parameter hydrologic model to a basin that will perform at least as well, in general, as a lumped total catchment area model measured by mean daily flow statistics. The hydrologic expertise required to do so is within the capability of experienced modelers, as no sophisticated tools are required.

2. The selected research watersheds exhibit complex hydrologic regimes which provide a meaningful test of each model's capability to simulate streamflow in either lumped or distributed configuration.

3. It is questionable whether more than two zones are necessary or advisable for watershed less than 1000 mi^2.

4. There is strong indication that a significant improvement in storm flow simulation may be obtained using multi-zones for basins subjected to intense convective rainstorms, and the improvement is possible even when the rain gage network is not sufficiently dense across the basin to define the storm pattern closely.

5. If rainfall variability across the basin is less than half an inch, there probably will be some simulation degeneration when using a multi-zone model instead of a total area catchment model, but the

percent degradation is small. This problem may be due more to model fitting technique than to model operational mode.

6. A distributed input model will mostly reduce peak flow error and improve peak timing, whereas the distributed input-distributed parameter model is more apt to improve rise volumes. Both multi-zone models may possibly degrade low flow simulation, though evidence indicates such a problem occurs chiefly if more than two zones are utilized. Regardless, the distributed input-distributed parameter model appears to reconstitute low flows better than the distributed input model, perhaps indicating the use of more physically realistic parameters. It is possible that with judicious reworking of the zone boundaries and time-delay histogram, the distributed input-distributed parameter model could prove superior to either the total area model or distributed input version throughout the full range of flows.

7. The improvement in simulation brought about by a multi-zone model is due to its capability of handling sub-area storm differences and sub-area soil moisture accounting, resulting in the computation of more accurate runoff depths. And the degree of improvement is somewhat proportional to the degree of rainfall variablility.

8. While mean daily flows are adequate for the general purpose of model calibration, they are inadequate for model research if the object is to monitor real time behavior of a hydrologic model. Standard statistical measures utilizing mean daily flow data are not sufficient to gage the full impact on simulation of a hydrologic model structured to account for the spatial variability of rainfall and parameters. More sophisticated statistics, as used in this study, are required for the task.

CHAPTER VIII

SUGGESTIONS FOR FUTURE STUDY

Based on experience gained from this investigation, the following suggestions regarding future multi-zone modeling research are offered:

1. There is a dire need for some measure of the precipitation gage network (density and distribution of gages) required before a multi-zone modeling attempt is warranted.

2. The accuracy of potential evapotranspiration demand required to best model a watershed remains unknown. In view of the fact that ET is a major loss function in the hydrologic cycle, and that one may possibly fit a model just as well to a 30-year normal PE curve as to real time computed PE, research here is in order. This aspect of modeling needs to be investigated whether one desires to use a distributed model or not.

3. The best method of breaking a catchment down into zones is not known. The number and location of the zones may well be a deciding factor in determining distributed model performance, so here some concrete guidance would be most welcome.

4. The development of techniques to determine optimal parameter values for each zone is sorely needed--a tall order, since there still exists the same need for lumped models with only one parameter set.

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APPENDIXES

Appendix A is a source listing of the Fortran V computer program written for the UNIVAC 1108 computer. The program requires approximately 37,000 words of 1108 core and is capable of handling up to five zones per basin when run as a multi-zone hydrologic model. The program utilizes the Sacramento Model soil-moisture accounting system (subrouting LAND) for either lumped mode (total catchment area) operation or distributed mode (multi-zone) operation. In distributed mode, the program will handle up to five zones per basin. Subroutine CHANNEL will accept either a fixed K or variable K for storage attenuation factor. Appendix B is a sample set (partial) of input data. The input data are file organized by month and data type.

APPENDIX A

THE HYDROLOGIC MODEL COMPUTER PROGRAM

*BOX .SACSIMFEICHS. HYDROLOGIC MODEL SIMULATION PROGRAM. OUTPUT FEICH.

```
MM        MM      NN        NN      WW        WW        SSSSSSSS        MM        MM      555555555555
MMM      MMM      NNN       NN      WW        WW       SSSSSSSSSS       MMM      MMM      555555555555
MMMM    MMMM      NNNN      NN      WW        WW      SS        SS      MMMM    MMMM      55
MMMMM  MMMMM      NNNNN     NN      WW        WW      SSS       SS      MMMMM  MMMMM      55
MM MMMMMM MM      NN NNN    NN      WW        WW        SSS             MM MMMMMM MM      55
MM  MMMM  MM      NN  NNN   NN      WW   WW   WW          SSS           MM  MMMM  MM      5555555555
MM   MM   MM      NN   NNN  NN      WW  WWWW  WW            SSS         MM   MM   MM      55555555555
MM        MM      NN    NNN NN      WW WWWWWW WW              SSS       MM        MM                55
MM        MM      NN     NNNNN      WWWWW  WWWWW      SS        SS      MM        MM                55
MM        MM      NN      NNNN      WWWW    WWWW      SS        SS      MM        MM      55        55
MM        MM      NN       NNN      WWW      WWW       SSSSSSSSSS       MM        MM       5555555555
MM        MM      NN        NN      WW        WW        SSSSSSSS        MM        MM        55555555

    0000             333333            999999            888888            666666            333333
  00000000         3333333333        9999999999        8888888888        6666666666        3333333333
 000    000       333      333      99        99      88        88      666       66      333      333
000      000      33        33      99        99      88        88      66                33        33
00        00                33      99        99       88     88        66                          33
00        00             333         99999999999         888888         66 6666666               333
00        00             333          9999999 99       8888888888       66666666666              333
00        00                33                99      888      888      66        66                33
000      000      33        33                99      88        88      66        66      33        33
 000    000       333      333      99        99      888      888      66        66      333      333
  00000000         3333333333        9999999999        8888888888        6666666666        3333333333
    0000             333333            999999           88888888           666666            333333

  SSSSSSSS          AAAAAAAA          CCCCCCCC          SSSSSSSS           IIIIII         MM        MM
 SSSSSSSSSS        AAAAAAAAAA        CCCCCCCCCC        SSSSSSSSSS          IIIIII         MMM      MMM
SS        SS      AA        AA      CC        CC      SS        SS           II           MMMM    MMMM
SSS       SS      AA        AA      CC        CC      SSS       SS           II           MMMMM  MMMMM
  SSS             AA        AA      CC                  SSS                  II           MM MMMMMM MM
    SSS           AAAAAAAAAAAA      CC                    SSS                II           MM  MMMM  MM
      SSS         AAAAAAAAAAAA      CC                      SSS              II           MM   MM   MM
        SSS       AA        AA      CC                        SSS            II           MM        MM
SS        SS      AA        AA      CC        CC      SS        SS           II           MM        MM
SS        SS      AA        AA      CC        CC      SS        SS           II           MM        MM
 SSSSSSSSSS       AA        AA       CCCCCCCCCC        SSSSSSSSSS          IIIIII         MM        MM
  SSSSSSSS        AA        AA        CCCCCCCC          SSSSSSSS           IIIIII         MM        MM

FFFFFFFFFFFF      EEEEEEEEEEEE         IIIIII           CCCCCCCC        HH        HH        SSSSSSSS
FFFFFFFFFFFF      EEEEEEEEEEEE         IIIIII          CCCCCCCCCC       HH        HH       SSSSSSSSSS
FF                EE                     II           CC        CC      HH        HH      SS        SS
FF                EE                     II           CC        CC      HH        HH      SSS       SS
FF                EE                     II           CC                HH        HH        SSS
FFFFFFFF          EEEEEEEE               II           CC                HHHHHHHHHHHH
FFFFFFFF          EEEEEEEE               II           CC                HHHHHHHHHHHH
FF                EE                     II           CC                HH        HH              SSS
FF                EE                     II           CC        CC      HH        HH      SS        SS
FF                EE                     II           CC        CC      HH        HH      SS        SS
FF                EEEEEEEEEEEE         IIIIII          CCCCCCCCCC       HH        HH       SSSSSSSSSS
FF                EEEEEEEEEEEE         IIIIII           CCCCCCCC        HH        HH        SSSSSSSS
```

●PRT,TL
FURPUR27R1C R72R1B 04/14/77 11:06:16

MORRIS*TPF$(0)   ELEMENT TABLE

D	NAME	VERSION	TYPE	DATE	TIME	SEQ #	SIZE-PRE	.TEXT	(CYCLE	WORD)	PSRMODE	LOCATION
	FS2INP		ELT SYMB	14 JAN 75	13:07:21	1		121	5	0	1	1792
	VPISUM		ELT SYMB	14 JAN 75	13:07:31	2		188	5	0	1	1913
	SNOWPM		FOR SYMB	09 JAN 75	09:35:01	3		34	5	2	3	2101
	SNOWIN		FOR SYMB	09 JAN 75	09:35:27	4		14	5	2	3	2135
	SNOWOT		FOR SYMB	09 JAN 75	09:36:51	5		14	5	2	3	2149
	PACK		FOR SYMB	16 JAN 75	09:11:01	6		109	5	4	5	2163
	RFS2MAP		MAP SYMB	16 JAN 75	09:12:23	7		1	5	2	3	2272
	NSRFS2		ABSOLUTE	16 JAN 75	09:12:48	8		294				2273
	RFS2		FOR SYMB	22 JAN 75	17:34:34	9		65	5	6	5	2567
	RFS2		RELOCATABLE	22 JAN 75	17:34:43	10	2	46				2632
	MAP		MAP SYMB	22 JAN 75	17:34:45	11		1	5	0	1	2680
	MW0008		ABSOLUTE	22 JAN 75	17:34:55	12		295				2681
*	MAP4		MAP SYMB	11 APR 77	15:14:56	13		1	5	37	5	2976
*	MW0023		ABSOLUTE	11 APR 77	15:15:10	14		660				2977
	RFS4		FOR SYMB	11 APR 77	15:15:33	15		271	5	45	5	3637
	RFS4		RELOCATABLE	11 APR 77	15:15:38	16	4	49				3908
	LANDPM		FOR SYMB	11 APR 77	15:15:40	17		43	5	40	5	3961
	LANDPM		RELOCATABLE	11 APR 77	15:15:43	18	2	42				4004
	FLOWPM		FOR SYMB	11 APR 77	15:15:46	19		43	5	40	5	4048
	FLOWPM		RELOCATABLE	11 APR 77	15:15:49	20	2	40				4091
	INTAPE		FOR SYMB	11 APR 77	15:15:51	21		30	5	38	5	4133
	INTAPE		RELOCATABLE	11 APR 77	15:15:54	22	2	27				4163
	LAND		FOR SYMB	11 APR 77	15:15:57	23		94	5	38	5	4192
	LAND		RELOCATABLE	11 APR 77	15:16:02	24	2	54				4286
	CHANEL		FOR SYMB	11 APR 77	15:16:04	25		61	5	38	5	4342
	CHANEL		RELOCATABLE	11 APR 77	15:16:09	26	2	37				4403
	LANDOT		FOR SYMB	11 APR 77	15:16:10	27		16	5	38	5	4442
	LANDOT		RELOCATABLE	11 APR 77	15:16:12	28	2	7				4458
	CHANOT		FOR SYMB	11 APR 77	15:16:14	29		23	5	38	5	4467
	CHANOT		RELOCATABLE	11 APR 77	15:16:16	30	2	13				4490
	FLOWOT		FOR SYMB	11 APR 77	15:16:18	31		21	5	38	5	4505
	FLOWOT		RELOCATABLE	11 APR 77	15:16:21	32	2	20				4526
	SUMARY		FOR SYMB	11 APR 77	15:16:22	33		50	5	39	5	4548
	SUMARY		RELOCATABLE	11 APR 77	15:16:27	34	2	54				4598
	STASUM		FOR SYMB	11 APR 77	15:16:30	35		256	5	41	5	4654
	STASUM		RELOCATABLE	11 APR 77	15:16:41	36	2	141				4910
	DAILY		FOR SYMB	11 APR 77	15:16:43	37		26	5	39	5	5053
	DAILY		RELOCATABLE	11 APR 77	15:16:46	38	2	26				5079
	LPLOT		FOR SYMB	11 APR 77	15:16:47	39		22	5	39	5	5107
	LPLOT		RELOCATABLE	11 APR 77	15:16:50	40	2	21				5129
	SNOW		FOR SYMB	11 APR 77	15:16:51	41		2	5	37	5	5152
	SNOW		RELOCATABLE	11 APR 77	15:16:53	42	2	3				5154
	MAP4		MAP SYMB	11 APR 77	15:16:58	43		1	5	38	5	5159
	MW0023		ABSOLUTE	11 APR 77	15:17:12	44		660				5160
NEXT AVAILABLE LOCATION-												5820

ASSEMBLER PROCEDURE TABLE EMPTY

COBOL PROCEDURE TABLE EMPTY

FORTRAN PROCEDURE TABLE EMPTY

ENTRY POINT TABLE

D	NAME	LINK	D	NAME	LINK	D	NAME	LINK	D	NAME	LINK	D	NAME	LINK
	CHANEL	26		CHANOT	30		DAILY	38		FLOWOT	32		FLOWPM	20
	FORMAIN$	16		FORMAIN$	10		INTAPE	22		LAND	24		LANDOT	28
	LANDPM	18		LPLOT	40		PACK	42		SNOW	42		SNOWIN	42
	SNOWOT	42		SNOWPM	42		STASUM	36		SUMARY	34			

●PRT.S .RFS4

MORRIS*TPF$(0).RFS4

```
C      PROGRAM SACSIM (INPUT,OUTPUT,PUNCH,TAPE1,TAPE2,TAPE3,TAPE4)
C**********************************************************************
C      THIS HYDROLOGIC MODEL SIMULATION PROGRAM UTILIZES A MODIFIED SACRAMENTO
C      SOIL MOISTURE ACCOUNTING SYSTEM WITH TIME DELAY HISTOGRAM TO DISTRIBUTE
C      RUNOFF VOLUMES.  PROGRAM MAY BE RUN IN TOTAL AREA CATCHMENT MODE OR
C      DISTRIBUTED INPUT-DISTRIBUTED PARAMETER MODE.
C**********************************************************************
C      PROGRAM IS CURRENTLY DIMENSIONED FOR THE FOLLOWING
C
C       5  MAP AREAS
C       5  MAT AREAS
C       2  PE STATIONS
C       3  STREAMFLOW-POINTS (NOT INCLUDING UPSTREAM INFLOW POINTS)
C       3  UPSTREAM INFLOW POINTS FROM OUTSIDE AREA
C      30  VALUES IN TIME-DELAY HISTOGRAM
C       3  UPSTREAM INFLOW POINTS TO A LOCAL AREA
C      10  POINTS TO DEFINE VARIABLE K AND LAG CURVE
C      10  DAYS--240 HOURS OF MAXIMUM LAG IS PERMITTED IN CARRYOVER ARRAYS
C                THIS IS THE MAXIMUM CONSTANT PLUS VARIABLE LAG PERMITTED
C               E.G.   IF THERE ARE 20 VALUES IN TIME DELAY HISTOGRAM
C                     THIS GIVES CONSTANT LAG OF 5.0 DAYS, THUS MAX. VARIABLE
C                     LAG ORDINATE IS 5.0 DAYS.
C**********************************************************************
C
C      THIS PROGRAM UTILIZES THREE K ROUTING COEFFICIENTS.
C      FOR HEADWATER AND LOCAL CATCHMENTS, THE KS1 (FIXED K) IS APPLIED TO THE
C      INFLOW HISTOGRAM (NO VRBL K ALLOWED).  FOR REACH ROUTING (TRANSPORTED
C      WATER) THE KS2 (FIXED K) IS APPLIED, OR KS2V (VRBL K), IF APPLICABLE,
C      IS APPLIED.
C
C**********************************************************************
C                    VERIFICATION PROGRAM WITH SNOW - INPUT SUMMARY




C          INPUT SUMMARY FOR VERIFICATION
C**********************************************************************
CCARD NO. FORMAT    CONTENTS
C**********************************************************************
C   1      20A4     BASIC RUN INFORMATION SUCH AS DATE,ETC.
C**********************************************************************
C   2      20A4     BASIN NAME
C**********************************************************************
C   3        I5     NUMBER OF MAP AREAS USED IN RUN (NGAGES)
C            I5     NO. OF PE STATIONS USED (NPEGS)
C            I5     NO. OF STREAM-FLOW-POINTS USED (NPTS)
C            I5     NO. OF UPSTREAM INFLOW POINTS NEEDED FROM OUTSIDE
C                       AREA BEING RUN (NPTSUP)
C**********************************************************************
C   4        I5     NUMBER OF MAP AREAS ON INPUT TAPE
C            I5     NO. OF PE STATIONS ON TAPE
C            I5     NO. OF MEAN DAILY FLOW-POINTS ON TAPE
C            I5     NO. OF POINTS WITH OBSERVED SIX-HOUR DISCHARGE
C                       THAT ARE ON TAPE
C            I5     NO. OF UPSTREAM INFLOW FROM OUTSIDE RUN AREA
```

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C                            ON TAPE
C************************************************************************
C   5         I5      FIRST MONTH OF RUN
C             I5      FIRST YEAR OF RUN (LAST 2 DIGITS ONLY)
C             I5      LAST MONTH
C             I5      LAST YEAR (2 DIGITS)
C************************************************************************
C   6       16I5      IDENTIFIES THE MAP AREAS ON TAPE TO BE USED IN THE RUN.
C                          ALSO DEFINES THE PRECIP. AREA ORDER FOR THE RUN.
C                          1 TO (NGAGES) VALUES ARE NEEDED.
C                     E.G.    5 MAP AREAS ON TAPE,(NGAGES)=3, CARD 6=4,1,5
C                       THEN THE 4 TH MAP RECORD ON TAPE WILL BE MAP AREA NO. 1
C                                1 ST MAP RECORD ON TAPE WILL BE MAP AREA NO. 2
C                                5 TH MAP RECORD ON TAPE WILL BE MAP AREA NO. 3
C************************************************************************
C   7       10A4      NAME OF PE STATION
C        10X,3A4      IDENTIFICATION CODE FOR PE DATA STATION
C    (REPEAT CARD 7 FOR EACH PE STATION(1 TO NPEGS))--ORDER OF READ DETERMINES
C                          PE STATION NUMBER FOR THE RUN)
C          NOTE.....CARD 7 ONLY NEEDED IF NPEGS IS GREATER THAN ZERO.
C************************************************************************
C   8       16I5      SAME AS CARD 6 ONLY FOR PE STATIONS.
C          NOTE.....CARD 8 ONLY NEEDED IF NPEGS IS GREATER THAN ZERO.
C************************************************************************
C   9       16I5      ASSOCIATES PE STATIONS TO MAP AREAS
C                          1 TO (NGAGES) VALUES ARE NEEDED
C                     E.G. (NGAGES)=3,(NPEGS)=2, CARD  9=2,1,2
C                               THEN THE 1ST PRECIP AREA WILL USE PE FROM NO.2
C                                                                PE STATION
C                                    THE 2ND PRECIP AREA WILL USE PE FROM NO.1
C                                                                PE STATION
C                                    THE 3RD PRECIP AREA WILL USE PE FROM NO.2
C                                                                PE STATION
C************************************************************************
C  10       16I5      SAME AS CARD 6 ONLY FOR MEAN DAILY FLOW STATIONS
C                          (VALUE =0 IF NO M.D.F. FOR A PARTICULAR FLOW-POINT)
C************************************************************************
C  11       16I5      SAME AS CARD 6 ONLY FOR SIX HOUR OBSERVED DISCHARGE
C                          (VALUE =0 IF NO DISCHARGE FOR A PARTICULAR FLOW-POINT)
C************************************************************************
C  11A      16I5      SAME AS CARD 6 ONLY FOR UPSTREAM INFLOW STATIONS
C                        FROM OUTSIDE CURRENT RUN AREA
C                          (ONLY NEEDED IF NO. OF UPSTREAM INFLOWS ON TAPE.GT.0)
C************************************************************************
C  12         I5      =1 STORE CHANNEL INFLOW ON TAPE,  =0 DO NOT STORE.
C             I5      =1 DO ROUTING ONLY USING CHANNEL INFLOWS PREVIOUSLY STORED
C                               ON TAPE    =0 NO
C             I5      =1 SAVE 6 HOUR FLOW AT EACH FLOW POINT ON TAPE FOR USE
C                          AS  UPSTREAM INFLOWS LATER    =0 NO
C             I5      =1 PLOT SIX HOUR FLOW FOR ALL PERIODS WHEN OBSERVED IS
C                               READ IN.        =0 NO
C             I5      CONTROLS TYPE OF WATER YEAR MEAN DAILY FLOW PLOT(S).
C                          =0, SEMI-LOG PLOT ONLY
C                          =1, ARITHMETIC PLOT ONLY
C                          =2, BOTH ARITHMETIC AND SEMI-LOG PLOTS.
C             I5      TAPE NO. OF CHANNEL INFLOW TAPE
C             I5      TAPE NO. OF PRECIPITATION TAPE
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C                  I5     TAPE NO. OF MEAN DAILY FLOW TAPE
C                  I5     TAPE NO. OF SIX HOUR OBSERVED DISCHARGE TAPE
C                  I5     TAPE NO. OF PE TAPE
C                  I5     TAPE NO. OF SNOW DATA (TEMPERATURE-WATER EQUIVALENT)
C                  I5     TAPE NO. FOR SAVING SIX HOUR FLOWS AS FUTURE
C                                    UPSTREAM INFLOWS
C                  I5     TAPE NO. FOR UPSTREAM INFLOWS FROM OUTSIDE RUN AREA
C                  I5     =0   NO  STATISTICAL SUMMARY
C                         =1   MULTIYEAR STATISTICAL SUMMARY PLUS PUNCH M.D.F. IN
C                                         STANDARD FORMAT
C                         =2   MULTIYEAR SUMMARY ONLY
C                         =3   YEARLY AND MULTIYEAR SUMMARY
C                         =4   YEARLY PLUS MULTIYEAR PLUS PUNCH M.D.F. CARDS
C                  I5     =1 OUTPUT MONTHLY FLOW VOLUMES AND MOISTURE STORAGES, =0 NO
C***********************************************************************
C  13              I5     =1 SNOW IS TO BE INCLUDED, =0 NO SNOW COMPUTATIONS.
C                  I5     =1 OUTPUT WATER YEAR SIMULATED DAILY FLOW SUMMARY TABLE,
C                              =0 NO TABLE OUTPUT
C                  I5     =1 OUTPUT DETAILED SOIL MOISTURE OUTPUT FOR SELECTED MONTHS,
C                              =0 NO DETAILED OUTPUT
C***********************************************************************
C  14          16I5       MONTH AND YEAR (2 DIGITS) FOR WHICH DETAILED SOIL MOISTURE
C                              OUTPUT IS WANTED.  (UP TO 8 MONTHS CAN BE OBTAINED)
C                         (THIS CARD ONLY NEEDED IF DETAILED SOIL MOISTURE OUTPUT
C                              IS ASKED FOR)
C***********************************************************************
C***********************************************************************
C**NOTE** REPEAT CARDS 15 THROUGH 18 FOR EACH MAP AREA.
C***********************************************************************
C  15             3A4     AREA IDENTIFICATION
C              3X,5A4     AREA NAME
C                F5.2     PRECIPITATION ADJUSTMENT FACTOR (PXADJ)
C                F5.2     ET-DEMAND ADJUSTMENT FACTOR (PEADJ)
C                F5.0     UPPER ZONE TENSION WATER CAPACITY(UZTWM) IN MILLIMETERS.
C                F5.0     UPPER ZONE FREE WATER CAPACITY (UZFWM) IN MILLIMETERS.
C                F5.2     (UZK)-FRACTION OF UZFWC WHICH IS DRAINED IN ONE DAY.
C                F5.2     (PCTIM) MINIMUM IMPERVIOUS AREA--DECIMAL FRACTION
C                F5.2     (ADIMP) ADDITIONAL IMPERVIOUS AREA--DECIMAL FRACTION
C                F5.2     (SARVA) DECIMAL FRACTION OF STREAMS AND RIPARIAN VEGETATION.
C***********************************************************************
C  16             3A4     AREA IDENTIFICATION
C            8X,F5.1      (ZPERC) ZPERC*(1+PBASE) IS THE MAXIMUM PERCOLATION.
C                F5.1     (REXP) EXPONENT THE PERCOLATION EQUATION.
C                F5.0     LOWER ZONE TENSION WATER CAPACITY (LZTWM) IN MILLIMETERS.
C                F5.0     LOWER ZONE FREE SUPPLEMENTAL CAPACITY (LZFSM) IN MILLIMETERS
C                F5.0     LOWER ZONE FREE PRIMARY CAPACITY (LZFPM) IN MILLIMETERS.
C       NOTE....LZFSM AND LZFPM ARE INPUT AS TOTAL AREAL VALUES AND NOT AS
C                         JUST THE VISIBLE PORTION.
C                F5.2     (LZSK) FRACTION OF LZFSC DRAINED IN ONE DAY.
C                F5.2     (LZPK) FRACTION OF LZFPC DRAINED IN ONE DAY.
C                F5.2     (PFREE) DECIMAL FRACTION OF PERCOLATED WATER WHICH ALWAYS
C                              GOES DIRECTLY TO LOWER ZONE FREE WATER STORAGES.
C                F5.2     (RSERV) DECIMAL FRACTION OF LOWER ZONE FREE WATER WHICH
C                              CANNOT BE TRANSFERED TO LZTWC.
C                F5.2     (SIDE) RATIO OF NON-CHANNEL BASEFLOW TO CHANNEL BASEFLOW.
C***********************************************************************
C  17             3A4     AREA IDENTIFICATION
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C              8X.      ET-DEMAND (IN MM/DAY) OR PE ADJUSTMENT ON THE 16TH OF EACH
C            12F5.2            MONTH (JAN.-DEC.) IF NO PE DATA ARE INPUT FOR THE
C                              AREA THEN CARD 17 IS ET-DEMAND. IF PE DATA ARE INPUT
C                              FOR THE AREA THEN CARD 17 MUST CONTAIN PE ADJUSTMENTS.
C                              THE ET-DEMAND OR PE ADJUSTMENTS USED EACH DAY IN THE
C                              PROGRAM ARE COMPUTED BY LINEAR INTERPOLATION BETWEEN
C                              THE 16TH OF EACH MONTH.
C*****************************************************************************
C  18          3A4      AREA IDENTIFICATION
C        NOTE....THIS CARD CONTAINS THE INITIAL SOIL MOISTURE CONTENTS FOR EACH
C                   STORAGE ZONE IN MILLIMETERS.
C          8X,F5.0      UPPER ZONE TENSION WATER CONTENTS (UZTWC)
C             F5.0      UPPER ZONE FREE WATER CONTENTS (UZFWC)
C             F5.0      LOWER ZONE TENSION WATER CONTENTS (LZTWC
C             F5.0      LOWER ZONE FREE SUPPLEMENTAL CONTENTS (LZFSC)
C             F5.0      LOWER ZONE FREE PRIMARY CONTENTS (LZFPC)
C             F5.0      TENSION WATER CONTENTS OF THE AREA DEFINED BY ADIMP (ADIMC)
C                              IF NOT KNOWN USE ADIMC=UZTWC+LZTWC
C*****************************************************************************
C*****************************************************************************
C*****************************************************************************
C*********NOTE***********  THE FOLLOWING 200 SERIES CARDS ARE ONLY NEEDED
C**    IF SNOW IS INCLUDED.      DO NOT PUT IN OTHERWISE.    ******************
C*****************************************************************************
C 201           I5      PUNCH 1 IN COLUMN 5
C               I5      =1 OUTPUT DAILY SNOW QUANTITIES SUCH AS WATER-EQUIVALENT,
C                              SNOWFALL,HEAT EXCHANGE,ETC.
C                       =0 NO DAILY SNOW OUTPUT
C               I5      =1  OUTPUT SNOWPACK OUTFLOW ON TO TAPE.
C                       =0  DO NOT OUTPUT ON TO TAPE
C               I5      TAPE NUMBER TO WHICH SNOWPACK OUTFLOW IS TO BE WRITTEN
C*****************************************************************************
C 202           I5      NUMBER OF MAT AREAS USED IN THIS RUN (NTAG)
C               I5      NUMBER OF AREAS WITH OBSERVED WATER-EQUIVALENT  (NWEG)
C*****************************************************************************
C 203           I5      NUMBER OF MAT AREAS ON INPUT TAPE
C               I5      NUMBER OF OBS. AREAL WATER-EQUIVALENTS ON INPUT TAPE
C*****************************************************************************
C 204          5A4      NAME OF MAT AREA
C            F10.0      MEAN ELEVATION OF MAT AREA IN METERS
C            4F5.1      AIR TEMPERATURE LAPSE RATES FOR MID-6AM,6AM-NOON,
C                              NOON-6PM,6PM-MID. (DEG. C/100 METERS ELEV. CHANGE)
C                  NOTE..REPEAT THIS CARD FOR EACH MAT AREA. CARD ORDER
C                       DEFINES MAT ORDER NUMBER FOR THIS RUN.
C*****************************************************************************
C 205         16I5      IDENTIFIES THE MAT AREAS ON TAPE TO BE USED IN THIS RUN.
C                              1 TO (NTAG) VALUES ARE NEEDED.
C                       E.G. 5 MAT AREAS ON TAPE, NTAG=2 , CARD 205 = 4,2
C                              THEN THE 4 TH MAT RECORD ON TAPE IS THE TEMPERATURE
C                                             DATA FOR THE 1 ST MAT AREA.
C                                       2 ND MAT RECORD ON TAPE IS THE TEMPERATURE
C                                             DATA FOR THE 2 ND MAT AREA.
C*****************************************************************************
C 206         16I5      ASSOCIATES MAT AREAS TO MAP AREAS
C                              1 TO (NGAGES) VALUES ARE NEEDED
C                       E.G. (NGAGES)=3, (NTAG)=2,  CARD 206=2,1,1
C                              THEN THE 1 ST PRECIP AREA WILL USE AIR TEMPERATURE
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C                                      FROM MAT AREA NO.2
C                                2 ND PRECIP AREA WILL USE AIR TEMPERATURE
C                                      FROM MAT AREA NO.1
C                                3 RD PRECIP AREA WILL USE AIR TEMPERATURE
C                                      FROM MAT AREA NO.1
C*******************************************************************************
C NOTE..CARDS 207 THROUGH 209 ONLY NEEDED IF (NWEG.GT.0)
C*******************************************************************************
C 207       5A4     NAME OF OBSERVED WATER-EQUIVALENT MEASUREMENT AREA
C               NOTE..REPEAT THIS CARD FOR EACH OBS. WATER-EQUIVALENT AREA
C                     USED IN THIS RUN.  CARD ORDER DEFINES ORDER NO. FOR RUN.
C*******************************************************************************
C 208       1615    SAME AS CARD 205 ONLY FOR OBS. WATER-EQUIVALENT AREAS.
C*******************************************************************************
C 209       1615    SAME AS CARD 206 ONLY FOR OBS. WATER-EQUIVALENT AREAS.
C*******************************************************************************
C*******************************************************************************
C NOTE..REPEAT CARDS 210,211,212,213,214 FOR EACH MEAN PRECIPITATION AREA
C               USED IN THIS RUN (NGAGES)
C*******************************************************************************
C 210 20X,F10.0     MEAN AREA ELEVATION IN METERS
C           F5.2    PERCENT/100 OF AREA OVER WHICH EVAPOTRANSPIRATION CAN TAKE
C                        PLACE WHEN THERE IS COMPLETE AREAL SNOW COVER (EFC)
C           F5.2    MULTIPLYING FACTOR TO CORRECT FOR GAGE CATCH DEFICIENCY
C                        IN THE CASE OF SNOWFALL. (SCF)
C           F5.2    MAXIMUM NON-RAIN MELT FACTOR -- OCCURS ON JUNE 21. (MFMAX)
C           F5.2    MINIMUM NON-RAIN MELT FACTOR -- OCCURS ON DEC. 21. (MFMIN)
C           F5.2    MAXIMUM NEGATIVE MELT FACTOR -- (NMF)
C               NOTE..UNITS FOR MELT FACTORS ARE MM/DEG.C/SIX HOURS
C           F5.4    MEAN WIND FUNCTION VALUE DURING RAIN ON SNOW PERIODS
C                        UNITS ARE MILLIMETERS/MILLIBAR (UADJ)
C           F5.0    AREAL WATER EQUIVALENT (MILLIMETERS) ABOVE WHICH THERE IS
C                        ALWAYS COMPLETE AREAL SNOW COVER.  (SI)
C           F5.1    DAILY MELT AT THE SNOW-SOIL INTERFACE IN TENTHS OF A
C                        MILLIMETER. (DAYGM)
C           F5.1    LATITUDE OF AREA IN DEGREES NORTH. (ALAT)
C                        IF ALAT.LT.54.0 THEN THE SEASONAL MELT FACTOR
C                        VARIATION IS A SINE CURVE. IF ALAT.GE.54.0 THEN THE
C                        ALASKA SEASONAL MELT FACTOR VARIATION IS USED.
C*******************************************************************************
C 211               INITIAL VALUES OF SOME SNOW COVER VARIABLES.
C       20X,F5.0    ANTECEDENT SNOW TEMP. INDEX  (DEG. C)  (ATI)
C           F5.0    FREE WATER IN SNOW IN EXCESS OF THAT HELD AGAINST GRAVITY
C                        DRAINAGE  (MILLIMETERS)
C           F5.0    POINT SB ON AREAL DEPLETION CURVE  (MILLIMETERS)
C           F5.2    PERCENT/100 AREAL SNOW COVER AT POINT SB.
C           F5.0    POINT SBWS ON AREAL DEPLETION CURVE (MILLIMETERS)
C     NOTE..SEE CHAP. 3(HYDRO-17) FOR FURTHER DESCRIPTION OF THESE VARIABLES.
C*******************************************************************************
C 212               INITIAL VALUES OF MAJOR SNOW COVER VARIABLES
C       20X,F5.0    INITIAL WATER-EQUIVALENT OF SOLID PORTION OF THE
C                        SNOWPACK.   (MILLIMETERS)
C           F5.0    INITIAL NEGATIVE HEAT STORAGE  (MILLIMETERS)
C           F5.0    INITIAL AMOUNT OF FREE WATER HELD AGAINST GRAVITY
C                        DRAINAGE (MILLIMETERS). MAXIMUM EQUALS PERCENT LIQUID
C                        WATER HOLDING CAPACITY TIMES INITIAL WATER-EQUIVALENT.
C*******************************************************************************
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C***********************************************************************
C 213          ADDITIONAL SNOW PARAMETERS
C      20X,F5.0     MELT FACTOR BASE TEMPERATURE  (DEG. C) (MBASE)
C          F5.0     TEMPERATURE (DEG. C) TO DIVIDE RAIN FROM SNOW  (PXTEMP)
C                        IF AIR TEMPERATURE GREATER,THEN RAIN
C                        IF AIR TEMPERATURE LESS THAN OR EQUAL,THEN SNOW
C          F5.2     PERCENT/100 LIQUID WATER HOLDING CAPACITY  (PLWHC)
C                        MAXIMUM AMOUNT OF FREE WATER HELD AGAINST GRAVITY.
C          F5.2     ANTECEDENT SNOW TEMP. INDEX PARAMETER  (TIPM)
C                        (.GE.0.0 --.LE.1.0)
C***********************************************************************
C 214 20X,9F5.2     AREAL SNOW COVER DEPLETION CURVE
C                        PERCENT/100 AREAL EXTENT OF SNOW COVER AT
C                        WATER EQUIVALENT/AI RATIOS OF  0.1,0.2,0.3,0.4,0.5,
C                             0.6,0.7,0.8,0.9 (SEE HYDRO-17,3.3.3 FOR DEFINITION
C                             OF AI)    FOR RATIO=0.0  AREAL COVER=0.05
C                                           RATIO=1.0  AREAL COVER=1.00
C***********************************************************************
C***********************************************************************
C***********************************************************************
C**NOTE**CARD  19 IS ONLY NEEDED WHEN THE NUMBER OF UPSTREAM INFLOWS
C        FROM OUTSIDE THE AREA BEING RUN IS.GT.0 (NPTSUP.GT.0)
C  19       5A4     NAME OF UPSTREAM INFLOW POINT
C     10X,F10.0     AREA OF UPSTREAM INFLOW POINT  (TOTAL AREA ABOVE GAGE SQ.KM)
C       REPEAT CARD 19 FOR EACH UPSTREAM INFLOW POINT (1 TO NPTSUP))
C             ORDER OF CARDS DETERMINES FLOW-POINT NUMBER FOR RUN
C             FIRST UPSTREAM INFLOW POINT IS ASSIGNED FLOW-POINT NUMBER
C                   EQUAL TO (NPTS+1).     E.G. IF NPTS=3 THEN THE FIRST
C                   UPSTREAM INFLOW POINT BECOMES FLOW-POINT 4 FOR
C                   THE RUN.
C***********************************************************************
C***********************************************************************
C**NOTE** REPEAT CARDS 20 THROUGH 27 (IF ALL NEEDED) FOR EACH FLOW-POINT
C        WITHIN RUN AREA (NPTS)
C       ORDER OF CARDS DETERMINES FLOW-POINT NUMBER FOR THE RUN.
C       NOTE...ALL FLOW-POINTS UPSTREAM FROM GAGE MUST HAVE A SMALLER RUN
C            NUMBER THAN THE GIVEN GAGE--EXCEPT FOR UPSTREAM INFLOW-POINTS
C            FROM OUTSIDE THE AREA BEING RUN(SEE CARD 19)
C  20       5A4     NAME OF FLOW-POINT
C     10X,F10.0     TOTAL AREA ABOVE FLOW-POINT IN SQUARE KILOMETERS.
C         F5.2      CONSTANT K ROUTING IN HOURS.                  (KS1)
C            I5     =1 USE VARIABLE K   =0 NO    (FOR TRANSPORTED WATER)
C            I5     =1 USE VARIABLE LAG =0 NO    (FOR TRANSPORTED WATER)
C            I5     ROUTING INTERVAL IN HOURS  (MUST=6 FOR NOW)
C            I5     NO. OF VALUES  IN TIME-DELAY HISTOGRAM FOR LOCAL AREA
C            I5     NO. OF UPSTREAM  INFLOW POINTS TO LOCAL AREA (NUPIN)
C                        THESE CAN BE UPSTREAM INFLOWS FROM OUTSIDE OR
C                        INSIDE THE RUN AREA
C            I5     NO.OF POINTS TO DEFINE VARIABLE K VS OUTFLOW CURVE
C            I5     NO. OF POINTS TO DEFINE VARIABLE LAG VS INFLOW CURVE
C***********************************************************************
C
C   *NOTE*          CARD NO. 20A NEEDED ONLY IF NUPIN(IPT).GT.0
C
C  20A   30X
C        10F5.2     CONSTANT K FOR REACH (KS2(IPT))                   (KS2)
C***********************************************************************
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C  21    8F10.0     VARIABLE K VS.OUTFLOW CURVE IF NEEDED    K IN HOURS
C                        MAXIMUM POINTS TO DEFINE CURVE IS 10 (THUS 3 CARDS)
C                        VALUES READ IN PAIRS  (FLOW,K)
C                             SO 4 PAIRS OF (FLOW,K) CAN GO ON A CARD
C                        K AT ZERO FLOW MUST BE FIRST POINT
C                        CALCULATIONS USING K ARE BASED ON A LINEAR
C                             INTERPOLATION BETWEEN POINTS
C                        K VALUE FOR HIGHEST DEFINED FLOW IS USED FOR
C                             ALL FLOWS ABOVE THAT DISCHARGE
C                        NOTE..DISCHARGE MUST BE IN CUBIC METERS/SEC.
C*******************************************************************************
C  22    8F10.0     VARIABLE LAG VS. INFLOW CURVE IF NEEDED   LAG IN HOURS
C                        MAX.PTS=10, VALUES IN PAIRS(FLOW,LAG), 4 PAIRS PER CARD
C                        LAG AT ZERO FLOW MUST BE FIRST POINT
C                        CALCULATIONS USING VARIABLE LAG ARE BASE ON
C                             LAGGING THE VOLUME OF FLOW IN THE INTERVAL
C                             FLOW(N) TO FLOW(N+1) BY THE AVERAGE LAG FOR
C                             THAT INTERVAL (LAG(N)+LAG(N+1))*0.5
C                        LAG VALUE FOR HIGHEST DEFINED FLOW IS USED FOR
C                             ALL FLOW ABOVE THAT DISCHARGE
C                        NOTE..DISCHARGE MUST BE IN CUBIC METERS/SEC.
C*******************************************************************************
C  23    30X,I5     =1 ROUTE OBSERVED OR BEST ESTIMATE OF OBSERVED
C                        DISCHARGE DOWNSTREAM.
C          F5.2     (SSOUT) CONSTANT CHANNEL LOSS RATE IN CUBIC METERS/SECOND.
C            I5     =1 DAILY PLOT IS NEEDED FOR THIS FLOW'POINT,  =0 NO PLOT.
C            I5     =1, DAILY PLOT ORDINATE WILL BE IN CMSD. (MM FOR SEMI-LOG)
C                   =0, DAILY PLOT ORDINATE WILL BE IN CFSD.(SEMI-LOG IN INCHES)
C         F10.0     MAXIMUM ORDINATE FOR DAILY ARITHMETIC PLOT.  UNITS ARE THE
C                          SAME AS FOR THE ARITHMETIC PLOT.
C          F5.0     BASE FOR FLOW INTERVAL CALCULATIONS IN THE STATISTICAL
C                        SUBROUTINE. UNITS ARE CMSD. (AS A GUIDE USE THE
C                        DAILY DISCHARGE THAT IS EXCEEDED ON APPROX. 25 PERCENT
C                        OF THE DAYS)
C         2X,I8     USGS STATION IDENTIFICATION NUMBER (8 DIGIT INTEGER NUMBER).
C                        THIS IS NEEDED IF STD. FMT. CARDS ARE TO BE PUNCHED.
C*******************************************************************************
C  24      30X,     TIME DELAY HISTOGRAM (MAX.NO OF POINTS=30)
C        10F5.2          HISTOGRAM IS FOR LOCAL AREA   SUMMATION OF VALUES=1.0
C                        USE MORE THAN ONE CARD IF NECESSARY(10 VALUES PER CARD)
C*******************************************************************************
C  25      30X,     MAP AREAS TO BE ASSIGNED TO EACH ELEMENT OF THE TIME-DELAY
C          10I5          HISTOGRAM ---  MAP AREAS DESIGNATED BY RUN NO. WHICH
C                        IS DETERMINED BY THE ORDER CARDS 15 TO 18 WERE READ.
C                        USE MORE THAN ONE CARD IF NECESSARY(10 VALUES PER CARD)
C*******************************************************************************
C  26      30X,     RUN NO. OF EACH UPSTREAM INFLOW POINT TO LOCAL AREA
C           5I5               NEEDED IF (NUPIN.GT.0)
C*******************************************************************************
C  27      30X,     CONSTANT LAG FOR EACH UPSTREAM INFLOW POINT
C          5F5.1        (LAG IN HOURS)    NEEDED IF (NUPIN.GT.0)
C               **NOTE** TOTAL LAG CONSISTS OF CONSTANT PLUS VARIABLE COMPONENT
C*******************************************************************************
C*******************************************************************************
C  28       4I5     NUMBER OF RECORDS TO SKIP ON TAPES 1 TO 4 TO POSITION
C                        THE TAPE CORRECTLY FOR THE INITIAL MONTH
C*******************************************************************************
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C***********************************************************************
C***********************************************************************
C     THE FOLLOWING SNOW INPUT  CARD  TELLS THE PROGRAM FOR WHICH MONTHS VALID
C          AIR TEMPERATURE DATA ARE AVAILABLE AND THUS WHICH MONTHS SNOW
C          COMPUTATIONS ARE TO BE MADE.     =1 VALID DATA AVAILABLE
C                                           =0 AIR TEMPERATURE DATA IS MISSING
C*****NOTE********  CARD 215 ONLY NEEDED IF SNOW IS INCLUDED.  ****************
C***********************************************************************
C 215       1215      VALID AIR TEMP. DATA INDICATOR-- MONTHS 1-12 (JAN-DEC)
C                          REPEAT CARD 215 FOR EACH WATER YEAR
C***********************************************************************
C***********************************************************************
C***********************************************************************
C***********************************************************************
C      DATA INPUT DESCRIPTION --------- SNOW NOT INCLUDED.
C
C          A.   BASIC DATA  CAN BE ON MORE THAN ONE TAPE  (IN ORDER BY MONTHS)
C                          IF ON ONE TAPE THE DATA MUST BE IN THE FOLLOWING ORDER.
C               1.   MAP DATA,  RECORD SIZE=124     SIX HOUR PCPN IN SEQUENTIAL
C                                                  ORDER FOR THE MONTH(INCHES)
C               2.   PE DATA,   RECORD SIZE=31      DAILY PE(INCHES)
C               3.   DAILY FLOW DATA,   RECORD SIZE=31  DAILY FLOWS FROM
C                             USGS WATER SUPPLY PAPERS.  (UNITS ARE CFSD)
C                         MISSING DATA IS READ IN AS NEGATIVE NUMBER
C               4.   SIX HOUR DISCHARGES,RECORD SIZE=124
C                         DISCHARGE AT 6 A.M.,NOON,6 P.M.,MID. FOR EACH DAY
C                              IN SEQ. ORDER FOR THE MONTH (UNITS ARE CFS)
C                         MISSING DATA IS READ IN AS NEGATIVE NUMBER
C               5.   UPSTREAM INFLOWS (SAME FORMAT AND UNITS AS 6-HOUR DISCHARGE)
C
C          B.  OTHER DATA IS EITHER GENERATED BY THE PROGRAM IN A PREVIOUS
C               RUN OR IN THE CASE OF UPSTREAM INFLOWS, THESE CAN BE GENERATED
C               BY A PREVIOUS RUN OR THE TAPE COULD BE PREPARED.
C                    IF PREPARED IT IS THE SAME FORMAT AS SIX HOUR DISCHARGES
C                         EXCEPT NO MISSING DATA IS ALLOWED.
C***********************************************************************
C***********************************************************************
C***********************************************************************
C      DATA INPUT DESCRIPTION ------- SNOW INCLUDED.
C
C          BASIC DATA CAN BE ON MORE THAN ONE TAPE  (IN ORDER BY MONTHS)
C               IF ON ONE TAPE,MUST BE IN THE FOLLOWING ORDER
C
C          1. MAP DATA -- RECORD SIZE 124
C          2. PE DATA -- RECORD SIZE 31
C          3. MAT DATA -- RECORD SIZE 124  (UNITS ARE DEG. F)
C               (NOTE..AIR TEMPERATURE CAN BE LOADED ON TO TAPE USING
C                O/H STANDARD FORMAT CARDS WITH PROGRAM NWSRFS2. (SEE
C                HYDRO-14,  APPENDIX E ) NOTE THAT AIR TEMPERATURE MUST BE
C                PUNCHED WITH FIELD LENGTH .EQ.3 ON O/H STD. FMT. CARDS.
C          4. OBSERVED AREAL WATER EQUIVALENT -- RECORD SIZE 31 (INCHES)
C               (NOTE..OBSERVED WATER EQUIVALENT DATA CAN BE LOADED ON TO TAPE
C              BY PROGRAM NWSRFS2, BY TREATING IT AS IF IT WERE MEAN DAILY FLOW.)
C          5. MEAN DAILY FLOW DATA -- RECORD SIZE 31
C          6. SIX HOUR DISCHARGE DATA -- RECORD SIZE 124
C          7. UPSTREAM INFLOWS -- RECORD SIZE 124
C***********************************************************************
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C*********************************************************************
C*********************************************************************
C*********************************************************************
C*********************************************************************
C MAIN VARIABLES
      INTEGER DA1,P61,DA2,P62,START(13),TN(4),SKIP(4)
      REAL MOCHAR(12)
      DIMENSION LASTDA(2,12),PENAME(3,10),MOSM(8,2)
C GENERAL PROGRAM VARIABLES
      INTEGER ROUTE,TRO,SNOW,SNOWA,YRIN,YR1,SGIN,TPTS,STORE,YEAR,PLT6HR,
     1SAVEFW,TSAVE,COMPAR,PTEST,PLOT,CTEST,      SIXIN,OBSER,STDA,STP6,
     2YR2,USGSID,STAT,PEG
      REAL INFRO
      COMMON/G/MONTH,MO1N,LAST,ROUTE,NGAGES,TRO,SNOW,SNOWA(12),YRIN,
     1NPEGS,YR1,NPTS,SGIN(3),TPTS,STORE,BASIN(20),YEAR,SSF(3,12),
     2SOF(3,12),PLT6HR,SAVEFW,DUMMY(4,31),TSAVE,COMPAR(3),PTEST,PLOT(3),
     3LINEP,INFRO(20),PLOTMX(3),CTEST,FSFLOW(3),USGSID(3),PEG(5),STAT,
     4YR2,AREA(6),SIXIN(3),OBSER(3),STDA(2,10),STP6(2,10),IYEAR1(3),IPT,
     5METRIC(3)
C BASIC DATA ARRAYS
      COMMON/BD/PX(5,31,4),TA(5,31,4),PE(3,31),RO(5,31,4),OFW6(3,31,4),
     1SFW6(3,31,4),UFW6(3,31,4),OFW24(3,31)
C DAILY PLOT DATA ARRAYS
      COMMON/PD/DPX(3,12,31),SFW24(3,12,31),WYFW24(3,12,31)
C TIME SERIES IDENTIFICATIONS AND DESCRIPTIONS.
      COMMON/TSID/AID(5,3),ANAME(5,5),PEID(3,3),FPNAME(6,5)
C MAIN AND INPUT VARIABLES
      INTEGER TFW24,TPX,PXIN,TFW6,TPE,PEIN,TTA,TAIN,RGIN,PEGIN,
     1      FW6IN,UPFWIN,TPTIN,TUPFW
      COMMON/MI/TFW24,TPX,PXIN,TFW6,TPE,PEIN,TTA,TAIN,RGIN(5),PEGIN(2),
     1         NPTSIN,FW6IN,UPFWIN,TPTIN(5),TUPFW
      COMMON/OUT/ISTOUT,ARMO(5,12,22)
      DATA START/1,32,60,91,121,152,182,213,244,274,305,335,366/
      DATA LASTDA/31,31,28,29,31,31,30,30,31,31,30,30,31,31,31,31,30,30,
     131,31,30,30,31,31/
      DATA MOCHAR/3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,4HJUNE,4HJULY,3HAUG,
     14HSEPT,3HOCT,3HNOV,3HDEC/
      CTEST=0                                                           OPERA
      PTEST=0                                                           OPERA
      CKTEST=0                                                          OPERA
      DO 100 I=1,4
100   TN(I)=0
C BASIC RUN INFORMATION                                                 OPERA
      READ 900,INFRO                                                    OPERA
      READ 900,BASIN                                                    OPERA
      READ 901,NGAGES,NPEGS,NPTS,NPTSUP                                 OPERA
      READ 901,PXIN,PEIN,NPTSIN,FW6IN,UPFWIN
      READ 901,MO1,YR1,MO2,YR2
      TPTS=NPTS+NPTSUP                                                  OPERA
      READ 901,(RGIN(I),I=1,NGAGES)
      IF (NPEGS.LT.1) GO TO 5
      DO 6 IRG=1,NPEGS                                                  OPERA
      READ 922,(PENAME(IRG,I),I=1,10),(PEID(IRG,I),I=1,3)
    6 CONTINUE
      READ 901,(PEGIN(I),I=1,NPEGS)
    5 READ 901,(PEG(I),I=1,NGAGES)
      READ 901,(SGIN(I),I=1,NPTS)
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      READ 901,(SIXIN(I),I=1,NPTS)
      IF (UPFWIN.GT.0) READ 901,(TPTIN(I),I=1,NPTSUP)
      READ 901,STORE,ROUTE,SAVEFW,PLT6HR,LINEP,TRO,TPX,TFW24,TFW6,TPE,
     1TTA,TSAVE,TUPFW,STAT,ISTOUT
      READ 901,SNOW,MDFTBL,IOUTSM
      MOSM(1,1)=0
      MOSM(1,2)=0
      IF (IOUTSM.GT.0) READ 901,((MOSM(ICOUNT,I),I=1,2),ICOUNT=1,8)
      ICOUNT=1
      IF (SNOW.EQ.0) TTA=0
      IF (STORE.EQ.1) ROUTE=0
      DO 10 IPT=1,NPTS
      IYEAR1(IPT)=0
      DO 10 MO=1,12
      SSF(IPT,MO)=0.0
      SOF(IPT,MO)=0.0
      DO 10 IDA=1,31
      DPX(IPT,MO,IDA)=0.0
      SFW24(IPT,MO,IDA)=0.0
   10 WYFW24(IPT,MO,IDA)=-0.00001
      DO 11 IRG=1,NGAGES
      DO 11 MO=1,12
      DO 11 I=1,22
   11 ARMO(IRG,MO,I)=0.0
C     OUTPUT RUN DATA                                                   OPERA
      PRINT 909                                                         OPERA
      DO 9 I=1,10                                                       OPERA
    9 PRINT 910                                                         OPERA
      PRINT 911,BASIN                                                   OPERA
      PRINT 914,MOCHAR(MO1),YR1,MOCHAR(MO2),YR2
      PRINT 912,INFRO                                                   OPERA
      PRINT 913                                                         OPERA
      PRINT 915,NGAGES,NPTS
      IF (NPEGS.LT.1) GO TO 8
      IRG=1
      PRINT 920,(PENAME(IRG,I),I=1,10),(PEID(IRG,I),I=1,3)
      IF (NPEGS.EQ.1) GO TO 8
      DO 7 IRG=2,NPEGS                                                  OPERA
    7 PRINT 921,(PENAME(IRG,I),I=1,10),(PEID(IRG,I),I=1,3)
    8 IF (SNOW.EQ.1) PRINT 902                                          OPERA
      IF (STORE.EQ.1) PRINT 919,TRO
      IF (SAVEFW.EQ.1) PRINT 903,TSAVE
C LAND PARAMETERS FOR EACH AREA                                         OPERA
      CALL LANDPM                                                       OPERA
C SNOW PARAMETERS FOR EACH AREA                                         OPERA
      IF (SNOW.EQ.0) GO TO 101                                          OPERA
      CALL SNOWPM(TAIN,NGAGES)
C CHANNEL PARAMETERS FOR EACH FLOW POINT                                OPERA
  101 CALL FLOWPM                                                       OPERA
C END OF RUN, AREA AND FLOW-POINT INPUT PARAMETERS
      READ 904,(SKIP(I),I=1,4)
      IF (SNOW.EQ.0) GO TO 108
      READ 907,SNOWA
  108 CONTINUE
      IF (TRO.GT.0) TN(TRO)=1
      IF (TPX.GT.0) TN(TPX)=1
      IF (TFW24.GT.0) TN(TFW24)=1
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      IF (TFW6.GT.0) TN(TFW6)=1
      IF (TPE.GT.0) TN(TPE)=1
      IF (TTA.GT.0) TN(TTA)=1
      IF (TSAVE.GT.0) TN(TSAVE)=1
      IF (TUPFW.GT.0) TN(TUPFW)=1
      DO 102 I=1,4
      IF (TN(I).EQ.0) GO TO 102
      REWIND I
      NN=SKIP(I)
      IF (NN.EQ.0) GO TO 102
      DO 103 N=1,NN
103   READ (I)
102   CONTINUE
      MONTH=MO1
      YEAR=YR1
      MOIN=MO1
      YRIN=YR1
99    DA1=1
      P61=1
      LEAPYR=1
      IF ((YRIN-4*(YRIN/4)).EQ.0) LEAPYR=2
      LAST=LASTDA(LEAPYR,MOIN)
      CALL INTAPE(MO1)
      MOIN=MOIN+1
      IF (MOIN.LE.12) GO TO 104
      MOIN=1
      YRIN=YRIN+1
104   DO 95 N=1,2
      DO 95 I=1,10
      STDA(N,I)=0
95    STP6(N,I)=0
      DA2=LAST
      P62=4
      IF (ROUTE.GT.0) GO TO 115
C COMPUTATION OF SNOW AND SOIL MOISTURE CONDITIONS FOR EACH AREA          OPERA
      DO 112 IRG=1,NGAGES                                                 OPERA
      IF (SNOW.EQ.0) GO TO 111                                            OPERA
      IF (SNOWA(MONTH).EQ.0) GO TO 111                                    OPERA
      CALL PACK(DA1,P61,DA2,P62,MONTH,YEAR,IRG)
111   CALL LAND (DA1,P61,DA2,P62,MOSM,ICOUNT,IRG)
112   CONTINUE                                                            OPERA
      IF ((ISTOUT.EQ.0).AND.(STORE.EQ.0)) GO TO 113
      CALL LANDOT
113   IF (SNOW.EQ.0) GO TO 115
      CALL SNOWOT(MOIN,MONTH,SNOWA,NGAGES)
115   DO 114 IPT=1,NPTS                                                   OPERA
      IF (PLT6HR.EQ.0) GO TO 116
      IF (SIXIN(IPT).EQ.0) GO TO 116
      I=0
      IC=0
      DO 90 IDA=DA1,DA2
      DO 90 I6=1,4
      IF(OFW6(IPT,IDA,I6).LT.0.0) GO TO 91
      IF (I.EQ.1) GO TO 90
      I=1
      IC=IC+1
      STDA(1,IC)=IDA
```

```
      STP6(1,IC)=I6
      GO TO 90
91    IF (I.EQ.0) GO TO 90
      IP6=I6-1
      ID=IDA
      IF (IP6.GT.0) GO TO 92
      IP6=4
      ID=IDA-1
92    STDA(2,IC)=ID
      STP6(2,IC)=IP6
      I=0
90    CONTINUE
      IF (I.EQ.0) GO TO 116
      STDA(2,IC)=DA2
      STP6(2,IC)=4
116   CALL CHANEL (DA1,P61,DA2,P62)                                     OPERA
      CALL CHANOT
C PUT SIX HOUR FLOW ON TAPE
      IF (SAVEFW.EQ.0) GO TO 119
      DO 118 IDA=1,31
      DO 118 IP6=1,4
      IF (OBSER(IPT).EQ.1) GO TO 1181
      DUMMY(IP6,IDA)=SFW6(IPT,IDA,IP6)*35.3147
      GO TO 118
 1181 DUMMY(IP6,IDA)=OFW6(IPT,IDA,IP6)*35.3147
118   CONTINUE
      WRITE (TSAVE) DUMMY
119   CONTINUE
114   CONTINUE                                                          OPERA
C WATER YEAR SUMMARY SECTION
      IF (MONTH.NE.9) GO TO 140
      CALL SUMARY(MDFTBL)
      DO 20 IPT=1,NPTS
      DO 20 MO=1,12
      SSF(IPT,MO)=0.0
      SOF(IPT,MO)=0.0
      DO 20 IDA=1,31
      DPX(IPT,MO,IDA)=0.0
      SFW24(IPT,MO,IDA)=0.0
 20   WYFW24(IPT,MO,IDA)=-0.00001
140   IF ((YEAR.EQ.YR2).AND.(MONTH.EQ.MO2)) GO TO 199
      MONTH=MOIN
      YEAR=YRIN
      GO TO 99
  199 IF (MONTH.NE.9) CALL SUMARY(MDFTBL)
C MAIN FORMAT STATEMENTS                                                OPERA
900   FORMAT (20A4)                                                     OPERA
901   FORMAT (16I5)                                                     OPERA
902   FORMAT (1H0,25X,15HSNOW IS INCLUDED)                              OPERA
903   FORMAT (1H0,25X,72HSIX HOUR FLOW TO BE ROUTED DOWNSTREAM FOR EACH
     1FLOW-POINT STORED ON TAPE,I2)
904   FORMAT (4I5)
907   FORMAT (12I5)
909   FORMAT (1H1)                                                      OPERA
910   FORMAT (1H0)                                                      OPERA
911   FORMAT (1H ,20X,20A4)                                             OPERA
912   FORMAT (1H0,20A4)                                                 OPERA
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      913   FORMAT (1H0,53X,21HBASIC RUN INFORMATION)                       OPERA
      914   FORMAT (1H0,10HRUN BEGINS,1X,A4,2H19,I2,5X,8HRUN ENDS,1X,A4,3H 19,
           1I2)
        915 FORMAT (1H0,10X,30HNUMBER OF PRECIPITATION AREAS=,I2,5X,
           122HNUMBER OF FLOW-POINTS=,I2)
      919   FORMAT (1H0,25X,29HCHANNEL INFLOW STORED ON TAPE,I2)
        920 FORMAT (1H0,10X,23HET DEMAND DATA USED ARE,5X,10A4,5X,
           17HI.D. IS,1X,3A4)
        921 FORMAT (1H ,41X,10A4,5X,7HI.D. IS,1X,3A4)
        922 FORMAT (10A4,10X,3A4)
            STOP                                                            OPERA
            END
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●PRT,S .LANDPM

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MORRIS*TPF$(0).LANDPM
      SUBROUTINE LANDPM
C INPUT OF PARAMETERS FOR LAND PHASE SUBROUTINE
      REAL LZTWM,LZFPM,LZFSM,LZSK,LZPK,LZTWC,LZFSC,LZFPC
      DIMENSION CID(3),EMO(12),ND(12),EC(365),ETD(5,12)
C GENERAL PROGRAM VARIABLES
      INTEGER ROUTE,TRO,SNOW,SNOWA,YRIN,YR1,SGIN,TPTS,STORE,YEAR,PLT6HR,
     1SAVEFW,TSAVE,COMPAR,PTEST,PLOT,CTEST,      SIXIN,OBSER,STDA,STP6,
     2YR2,USGSID,STAT,PEG
      REAL INFRO
      COMMON/G/MONTH,MOIN,LAST,ROUTE,NGAGES,TRO,SNOW,SNOWA(12),YRIN,
     1NPEGS,YR1,NPTS,SGIN(3),TPTS,STORE,BASIN(20),YEAR,SSF(3,12),
     2SOF(3,12),PLT6HR,SAVEFW,DUMMY(4,31),TSAVE,COMPAR(3),PTEST,PLOT(3),
     3LINEP,INFRO(20),PLOTMX(3),CTEST,FSFLOW(3),USGSID(3),PEG(5),STAT,
     4YR2,AREA(6),SIXIN(3),OBSER(3),STDA(2,10),STP6(2,10),IYEAR1(3),IPT,
     5METRIC(3)
C  SOIL MOISTURE ACCOUNTING VARIABLES.
      COMMON/SOIL/BAL(5),PL(5,18),VL(5,6),SL(5,10),E(5,12,31)
C TIME SERIES IDENTIFICATIONS AND DESCRIPTIONS.
      COMMON/TSID/AID(5,3),ANAME(5,5),PEID(3,3),FPNAME(6,5)
C SNOW AND LAND COMMON BLOCK
      COMMON/SL/COVER(5,31),EFC(5),PXADJ(5)
      DATA ND/31,28,31,30,31,30,31,31,30,31,30,31/
C***********************************************************************
      DO 100 IRG=1,NGAGES
      READ 900,(AID(IRG,I),I=1,3),(ANAME(IRG,I),I=1,5),
     1PXADJ(IRG),PEADJ,UZTWM,UZFWM,UZK,PCTIM,ADIMP,SARVA
  900 FORMAT(3A4,3X,5A4,2F5.2,2F5.0,4F5.2)
C     NOTE.....LOWER ZONE FREE WATER VOLUMES (CAPACITIES AND CONTENTS)
C         ARE ENTERED AS THE TOTAL AMOUNT ALREADY ADJUSTED FOR SIDE.
      READ 901,CID,ZPERC,REXP,LZTWM,LZFSM,LZFPM,LZSK,LZPK,
     1PFREE,RSERV,SIDE
  901 FORMAT(3A4,8X,2F5.1,3F5.0,5F5.2)
C      INSURE THAT CAPACITIES ARE NOT ZERO
      IF(UZTWM .LT. 0.1) UZTWM = 0.1
      IF(UZFWM .LT. 0.1) UZFWM = 0.1
      IF(LZTWM .LT. 0.1) LZTWM = 0.1
      IF(LZFSM .LT. 0.1) LZFSM = 0.1
      IF(LZFPM .LT. 0.1) LZFPM = 0.1
      DO 101 I=1,3
      IF (AID(IRG,I).EQ.CID(I))GO TO 101
      GO TO 109
  101 CONTINUE
      READ 902,CID,EMO
  902 FORMAT(3A4,8X,12F5.2)
      DO 102 I=1,3
      IF(AID(IRG,I).EQ.CID(I))GO TO 102
      GO TO 109
  102 CONTINUE
      READ 903,CID,UZTWC,UZFWC,LZTWC,LZFSC,LZFPC,ADIMC
  903 FORMAT(3A4,8X,6F5.0)
      DO 103 I=1,3
      IF(AID(IRG,I).EQ.CID(I))GO TO 103
      GO TO 109
  103 CONTINUE
      GO TO 104
C      PARAMETER INPUT IS OUT OF ORDER
```

```
  109 PRINT 919,(AID(IRG,I),I=1,3)
  919 FORMAT (1H1,27HLAND PARAMETER AREA I.D. IS,1X,3A4,5X,70HALL LAND P
     1ARAMETER INPUT CARDS FOR THAT AREA DO NOT HAVE THE SAME I.D.)
      STOP
  104 EFC(IRG)=0.0
      DO 105 IDA=1,31
  105 COVER(IRG,IDA)=0.0
      PL(IRG,1)=PXADJ(IRG)
      PL(IRG,2)=PEADJ
      PL(IRG,3)=UZTWM
      PL(IRG,4)=UZFWM
      PL(IRG,5)=UZK
      PL(IRG,6)=PCTIM
      PL(IRG,7)=ADIMP
      PL(IRG,8)=SARVA
      PL(IRG,9)=ZPERC
      PL(IRG,10)=REXP
      PL(IRG,11)=LZTWM
      PL(IRG,12)=LZFSM
      PL(IRG,13)=LZFPM
      PL(IRG,14)=LZSK
      PL(IRG,15)=LZPK
      PL(IRG,16)=PFREE
      PL(IRG,17)=RSERV
      PL(IRG,18)=SIDE
      VL(IRG,1)=UZTWC
      VL(IRG,2)=UZFWC
      VL(IRG,3)=LZTWC
      VL(IRG,4)=LZFSC
      VL(IRG,5)=LZFPC
      VL(IRG,6)=ADIMC
C*************************************************************************
C     COMPUTE ET DEMAND CURVE OR PE ADJUSTMENT CURVE
      ID=16
      EC(16)=EMO(1)
      DO 106 I=2,13
      NDAYS=ND(I-1)
      K=I-1
      M=I
      IF(I.EQ.13) M=1
      STEP=(EMO(M)-EMO(K))/NDAYS
      DO 106 L=1,NDAYS
      ID=ID+1
      IF(ID.GT.365)ID=ID-365
      IP=ID-1
      IF(IP.LT.1)IP=365
  106 EC(ID)=EC(IP)+STEP
      ID=1
      DO 107 MO=1,12
      NDAYS=ND(MO)
      DO 107 L=1,NDAYS
      E(IRG,MO,L)=EC(ID)
      ID=ID+1
  107 CONTINUE
      E(IRG,2,29)=E(IRG,2,28)
      DO 108 I=1,12
  108 ETD(IRG,I)=EMO(I)
```

```
  100 CONTINUE
C*****************************************************************************
C     PRINTOUT OF LAND PARAMETERS
      PRINT 904,BASIN
  904 FORMAT(1H1,35HSOIL-MOISTURE ACCOUNTING PARAMETERS,5X,20A4)
      PRINT 905,INFRO
  905 FORMAT(1H0,20A4)
      PRINT 920
  920 FORMAT (1H0,5X,38HCONTENT AND CAPACITY VALUES ARE IN MM.)
      PRINT 906
  906 FORMAT(1H0,40X,42H UPPER ZONE AND IMPERVIOUS AREA PARAMETERS)
      PRINT 907
  907 FORMAT(1H0,8HAREA NO.,3X,9HAREA I.D.,13X,9HAREA NAME,4X,6HPX-ADJ,
     12X,6HPE-ADJ,3X,5HUZTWM,3X,5HUZFWM,5X,3HUZK,
     23X,5HPCTIM,3X,5HADIMP,3X,5HSARVA)
      DO 110 IRG=1,NGAGES
      PRINT 908,IRG,(AID(IRG,I),I=1,3),(ANAME(IRG,I),I=1,5),
     1(PL(IRG,I),I=1,8)
  908 FORMAT(1H ,I5,3X,3A4,2X,5A4,F10.3,F8.3,2F8.0,4F8.3)
  110 CONTINUE
      PRINT 909
  909 FORMAT(1H0,40X,37 HPERCOLATION AND LOWER ZONE PARAMETERS)
      PRINT 910
  910 FORMAT(1H0,8HAREA NO.,3X,5HPBASE,3X,5HZPERC,4X,4HREXP,
     13X,5HLZTWM,3X,5HLZFSM,3X,5HLZFPM,4X,4HLZSK,
     24X,4HLZPK,3X,5HPFREE,3X,5HRSERV,4X,4HSIDE)
      DO 111 IRG=1,NGAGES
      PBASE=PL(IRG,12)*PL(IRG,14)+PL(IRG,13)*PL(IRG,15)
      PRINT 911,IRG,PBASE,(PL(IRG,I),I=9,18)
  911 FORMAT(1H ,I5,3X,F8.1,F8.1,F8.2,3F8.0,2F8.4,3F8.2)
  111 CONTINUE
      PRINT 912
  912 FORMAT(1H0,30X,53HPE-ADJUSTMENT OR ET-DEMAND FOR THE 16TH OF EACH
     1MONTH)
      PRINT 913,(I,I=1,12)
  913 FORMAT(1H0,8HAREA NO.,20X,12I6,5X,15HI.D. OF PE DATA)
      DO 112 IRG=1,NGAGES
      IGPE=PEG(IRG)
      IF(IGPE.GT.0)GO TO 113
      PRINT 914,IRG,(ETD(IRG,I),I=1,12)
  914 FORMAT(1H ,I5,3X,16HET-DEMAND-MM/DAY,4X,12F6.1)
      GO TO 112
  113 PRINT 915,IRG,(ETD(IRG,I),I=1,12),(PEID(IGPE,I),I=1,3)
  915 FORMAT(1H ,I5,3X,13HPE-ADJUSTMENT,7X,12F6.2,8X,3A4)
  112 CONTINUE
      PRINT 916
  916 FORMAT(1H0,40X,24HINITIAL STORAGE CONTENTS)
      PRINT 917
  917 FORMAT(1H0,8HAREA NO.,3X,5HUZTWC,3X,5HUZFWC,
     13X,5HLZTWC,3X,5HLZFSC,3X,5HLZFPC,3X,5HADIMC)
      DO 114 IRG=1,NGAGES
      PRINT 918,IRG,(VL(IRG,I),I=1,6)
  918 FORMAT(1H ,I5,3X,6F8.0)
  114 CONTINUE
      RETURN
      END
```

●PRT,S .FLOWPM

```
MORRIS*TPF$(0).FLOWPM
      SUBROUTINE FLOWPM
C FLOWPM VARIABLES
      INTEGER ELE
      REAL  INAREA
      DIMENSION FLOW(11),VKOL(11)
C GENERAL PROGRAM VARIABLES
      INTEGER ROUTE,TRO,SNOW,SNOWA,YRIN,YR1,SGIN,TPTS,STORE,YEAR,PLT6HR,
     1SAVEFW,TSAVE,COMPAR,PTEST,PLOT,CTEST,       SIXIN,OBSER,STDA,STP6,
     2YR2,USGSID,STAT,PEG
      REAL  INFRO
      COMMON/G/MONTH,MOIN,LAST,ROUTE,NGAGES,TRO,SNOW,SNOWA(12),YRIN,
     1NPEGS,YR1,NPTS,SGIN(3),TPTS,STORE,BASIN(20),YEAR,SSF(3,12),
     2SOF(3,12),PLT6HR,SAVEFW,DUMMY(4,31),TSAVE,COMPAR(3),PTEST,PLOT(3),
     3LINEP,INFRO(20),PLOTMX(3),CTEST,FSFLOW(3),USGSID(3),PEG(5),STAT,
     4YR2,AREA(6),SIXIN(3),OBSER(3),STDA(2,10),STP6(2,10),IYEARI(3),IPT,
     5METRIC(3)
C MAIN AND CHANEL VARIABLES
      INTEGER VARK,VARL,RINT,Z,GAGEAR
      REAL KS1,KS2,KINCRE,KS2V,LINCRE,LOCALI,INFLOL,LAG
      COMMON/CHAN/FWP41(3),KS1(3),KS2(3),VARK(3),VARL(3),
     1RINT(3),Z(3),NUPIN(3),KINCRE(3,10),KS2V(3,11),LINCRE(3,10),LAG
     2(3,10),TDELAY(3,30),GAGEAR(3,30),IFLOPT(3,3),UPLAG(3,3),CFSM(3),
     3PREVI1(3),LOCALI(3,42),TLAGI(3,42),TRANSI(3,42),MAXL(3),TLAGLI(3),
     4INFLOL(3,10),OTFLOK(3,11),NKPTS(3),NLPTS(3),PREVI2(3),SSOUT(3)
C TIME SERIES IDENTIFICATIONS AND DESCRIPTIONS.
      COMMON/TSID/AID(5,3),ANAME(5,5),PEID(3,3),FPNAME(6,5)
C INPUT OF PARAMETERS FOR CHANNEL SUBROUTINE
      IF (TPTS.EQ.NPTS) GO TO 97
      NN=NPTS+1
      DO 98 IPT=NN,TPTS
 98   READ 900,(FPNAME(IPT,I),I=1,5),AREA(IPT)
 97   DO 100 IPT=1,NPTS
      READ 900,(FPNAME(IPT,I),I=1,5),AREA(IPT),KS1(IPT),VARK(IPT),
     1VARL(IPT),RINT(IPT),Z(IPT),NUPIN(IPT),NK,NL
      IF(NUPIN(IPT).EQ.0)  GO TO 94
C CARD NO. 20A
      READ 904,KS2(IPT)
   94 IF(VARK(IPT).EQ.0)  GO TO 101
      KS2(IPT)=0.0
      NKPTS(IPT)=NK
      READ 901,(FLOW(I),VKOL(I),I=1,NK)
      IF (FLOW(1).NE.0.0)FLOW(1)=0.0
      FLOW(NK+1)=10000000.
      KK = NK + 1
      OTFLOK(IPT,KK)=10000000.
      KS2V(IPT,KK)=VKOL(NK)
      VKOL(NK+1)=VKOL(NK)
      DO 95 I=1,NK
      OTFLOK(IPT,I)=FLOW(I)
      KS2V(IPT,I)=VKOL(I)
      KINCRE(IPT,I)=(VKOL(I+1)-VKOL(I))/(FLOW(I+1)-FLOW(I))
   95 CONTINUE
 101  IF (VARL(IPT).EQ.0) GO TO 102
      NLPTS(IPT)=NL
      READ 901,(FLOW(I),VKOL(I),I=1,NL)
      IF (FLOW(1).NE.0.0)FLOW(1)=0.0
```

```
      FLOW(NL+1)=10000000.0
      VKOL(NL+1)=VKOL(NL)
      DO 96 I=1,NL
      INFLOL(IPT,I)=FLOW(I+!)
      LAG(IPT,I)=(VKOL(I)+VKOL(I+1))*0.5
      LINCRE (IPT,I)=FLOW(I+1)-FLOW(I)
   95 CONTINUE
  102 READ 903,OBSER(IPT),SSOUT(IPT),PLOT(IPT),METRIC(IPT),PLOTMX(IPT),
     1FSFLOW(IPT),USGSID(IPT)
      ELE=Z(IPT)
      IF (PLOT(IPT).EQ.0) GO TO 103
      PTEST=1
103   IF (SGIN(IPT).EQ.0) GO TO 111
      CTEST=1
      COMPAR(IPT)=1
      GO TO 113
111   COMPAR(IPT)=0
113   READ 904,(TDELAY(IPT,I),I=1,ELE)
      READ 905,(GAGEAR(IPT,I),I=1,ELE)
      NN=NUPIN(IPT)
      INAREA=0.0
      IF (NN.EQ.0) GO TO 105
      READ 905,(IFLOPT(IPT,I),I=1,NN)
      READ 906,(UPLAG(IPT,I),I=1,NN)
      DO 106 N=1,NN
      I=IFLOPT(IPT,N)
      INAREA=INAREA+AREA(I)
106   CONTINUE
  105 CFSM(IPT)=.046296*(AREA(IPT)-INAREA)
      MLAG=0
      IF (VARL(IPT).EQ.0) GO TO 107
      DO 108 I=1,NL
      IF (LAG(IPT,I).GT.MLAG) MLAG=LAG(IPT,I)
108   CONTINUE
107   MAXL(IPT)=ELE*RINT'IPT)+MLAG
      MAXL(IPT)=((MAXL(IPT)-1)/RINT(IPT))+1
      PREVI1(IPT)=0.0
      PREVI2(IPT)=0.0
      TLAGLI(IPT)=0.0
      FWP4I(IPT)=0.0
      IE=MAXL(IPT)+2
      DO 109 I=1,IE
      LOCALI(IPT,I)=0.0
      TLAGI(IPT,I)=0.0
109   TRANSI(IPT,I)=0.0
100   CONTINUE
C PRINTOUT OF CHANNEL PARAMETERS
      PRINT 907,BASIN
      PRINT 908,INFRO
      PRINT 909
      PRINT 910
      DO 120 IPT=1,NPTS
      ELE=Z(IPT)
      IE=ELE
      IF (IE.GT.10) IE=10
      PRINT 911,IPT,(FPNAME(IPT,I),I=1,5),AREA(IPT),KSI(IPT),SSOUT(IPT),
     1OBSER(IPT),COMPAR(IPT),SIXIN(IPT),(TDELAY(IPT,I),I=1,IE)
```

```
      IF (IE.EQ.ELE) GO TO 126
      PRINT 920,(TDELAY(IPT,I),I=11,ELE)
126   PRINT 912,(GAGEAR(IPT,I),I=1,IE)
      IF (IE.EQ.ELE) GO TO 127
      PRINT 921,(GAGEAR(IPT,I),I=11,ELE)
127   NN=NUPIN(IPT)
      IF (NN.EQ.0) GO TO 115
      PRINT 913,(IFLOPT(IPT,I),I=1,NN)
      PRINT 914,(UPLAG(IPT,I),I=1,NN)
      PRINT 9140,KS2(IPT)
115   CONTINUE
      IF (VARL(IPT).EQ.0) GO TO 116
      NL=NLPTS(IPT)
      FLOW (1)=0.0
      VKOL(NL+1)=LAG(IPT,NL)
      DO 117 I=1,NL
      FLOW(I+1)=INFLOL(IPT,I)
      J=NL-I+1
      VKOL(J)=2.0*LAG(IPT,J)-VKOL(J+1)
  117 CONTINUE
      PRINT 917,(FLOW(I),I=1,NL)
      PRINT 918,(VKOL(I),I=1,NL)
  116 IF (VARK(IPT).EQ.0) GO TO 120
      NK=NKPTS(IPT)
      DO 118 I=1,NK
      FLOW (I)=OTFLOK(IPT,I)
      VKOL(I)=KS2V(IPT,I)
  118 CONTINUE
      PRINT 917,(FLOW(I),I=1,NK)
      PRINT 919,(VKOL(I),I=1,NK)
120   CONTINUE
      IF (TPTS.EQ.NPTS) GO TO 110
      NN=NPTS+1
      PRINT 915
      DO 121 IPT=NN,TPTS
121   PRINT 916,IPT,(FPNAME(IPT,I),I=1,5),AREA(IPT)
110   CONTINUE
C FLOWPM FORMAT STATEMENTS
  900 FORMAT(5A4,10X,F10.0,F5.2,7I5)
  901 FORMAT(8F10.0)
  903 FORMAT (30X,I5,F5.2,2I5,F10.0,F5.0,2X,I8)
904   FORMAT (30X,10F5.2)
905   FORMAT (30X,10I5)
906   FORMAT (30X,5F5.1)
907   FORMAT (1H1,20X,20A4)
908   FORMAT (1H0,20A4)
909   FORMAT (1H0,45X,21HFLOW-POINT PARAMETERS)
  910 FORMAT (1H0,'NO.',4X'FLOW-POINT NAME',5X'AREA-SQ KM',5X'K',
     12X,5HSSOUT,1X,5HOBSER,1X,6HCOMPAR,1X,5HSIXIN,2X,10HHISTOGRAMS)
  911 FORMAT (1H ,I2,2X5A4,5XF8.2,F6.2,F7.2,I6,I7,I6,2X'TIME-DELAY',
     110F5.3)
  912 FORMAT (1H ,71X'GAGE AREA ',10I5)
913   FORMAT (1H ,75X,10HINFLOW-PTS,5I5)
914   FORMAT (1H ,75X,10HINFLOW LAG,5F5.1)
 9140 FORMAT (1H ,75X,10HKS2(REACH),F5.1)
915   FORMAT (1H0,34HFLOW-POINTS UPSTREAM FROM AREA ARE)
916   FORMAT (1H ,I3,3X,5A4,7X,F8.2)
```

```
  917 FORMAT (1H ,10X,4HFLOW,6X,10F10.0)
  918 FORMAT (1H ,10X,8HVAR. LAG,2X,10F10.1)
  919 FORMAT (1H ,10X,6HVAR. K,4X,10F10.1)
920   FORMAT (1H ,75X,10F5.3)
921   FORMAT (1H ,75X,10I5)
      RETURN
      END
```

●PRT,S   .INTAPE

```
MORRIS*TPF$(0).INTAPE
      SUBROUTINE INTAPE(MOI)
C SUBROUTINE TO INPUT ONE MONTH OF DATA FROM TAPE
C INTAPE VARIABLES
      INTEGER DI,D2
      DIMENSION DUMMA(31)
C GENERAL PROGRAM VARIABLES
      INTEGER ROUTE,TRO,SNOW,SNOWA,YRIN,YRI,SGIN,TPTS,STORE,YEAR,PLT6HR,
     1SAVEFW,TSAVE,COMPAR,PTEST,PLOT,CTEST,      SIXIN,OBSER,STDA,STP6,
     2YR2,USGSID,STAT,PEG
      REAL INFRO
      COMMON/G/MONTH,MOIN,LAST,ROUTE,NGAGES,TRO,SNOW,SNOWA(12),YRIN,
     1NPEGS,YRI,NPTS,SGIN(3),TPTS,STORE,BASIN(20),YEAR,SSF(3,12),
     2SOF(3,12),PLT6HR,SAVEFW,DUMMY(4,31),TSAVE,COMPAR(3),PTEST,PLOT(3),
     3LINEP,INFRO(20),PLOTMX(3),CTEST,FSFLOW(3),USGSID(3),PEG(5),STAT,
     4YR2,AREA(6),SIXIN(3),OBSER(3),STDA(2,10),STP6(2,10),IYEARI(3),IPT,
     5METRIC(3)
C MAIN AND INPUT VARIABLES
      INTEGER TFW24,TPX,PXIN,TFW6,TPE,PEIN,TTA,TAIN,RGIN,PEGIN,
     1      FW6IN,UPFWIN,TPTIN,TUPFW
      COMMON/MI/TFW24,TPX,PXIN,TFW6,TPE,PEIN,TTA,TAIN,RGIN(5),PEGIN(2),
     1         NPTSIN,FW6IN,UPFWIN,TPTIN(5),TUPFW
C BASIC DATA ARRAYS
      COMMON/BD/PX(5,31,4),TA(5,31,4),PE(3,31),RO(5,31,4),OFW6(3,31,4),
     1SFW6(3,31,4),UFW6(3,31,4),OFW24(3,31)
      DI=1
      D2=LAST
      IF (ROUTE.EQ.0) GO TO 100
      DO 101 IRG=1,NGAGES
      READ (TRO) DUMMY
      DO 102 IDA=DI,D2
      DO 102 I6=1,4
102   RO(IRG,IDA,I6)=DUMMY(I6,IDA)
101   CONTINUE
      IF (TFW24.NE.TPX) GO TO 130
      DO 131 I=1,PXIN
131   READ (TFW24)
      GO TO 132
130   IF (TFW6.NE.TPX) GO TO 132
      DO 133 I=1,PXIN
133   READ (TFW6)
132   IF (TFW24.NE.TPE) GO TO 134
      DO 135 I=1,PEIN
135   READ (TFW24)
      GO TO 136
134   IF (TFW6.NE.TPE) GO TO 136
      DO 137 I=1,PEIN
137   READ (TFW6)
136   IF (SNOW.EQ.0) GO TO 120
      IF (TFW24.NE.TTA) GO TO 138
      DO 139 I=1,TAIN
139   READ (TFW24)
      GO TO 120
138   IF (TFW6.NE.TTA) GO TO 120
      DO 140 I=1,TTA
140   READ(TFW6)
      GO TO 120
```

```
C SIX HOUR PRECIPITATION DATA
100    DO 103 IG=1,PXIN
       DO 104 I=1,NGAGES
       IF (RGIN(I).NE.IG) GO TO 104
       IRG=I
       GO TO 105
104    CONTINUE
       READ (TPX)
       GO TO 103
105    READ (TPX) DUMMY
       DO 106 IDA=D1,D2
       DO 106 I6=1,4
  106 PX(IRG,IDA,I6)=DUMMY(I6,IDA)*25.4
103    CONTINUE
C DAILY POTENTIAL EVAPOTRANSPIRATION
       IF (PEIN.LT.1) GO TO 110
       DO 107 IG=1,PEIN
       IF (NPEGS.LT.1) GO TO 111
       DO 108 I=1,NPEGS
       IF (PEGIN(I).NE.IG) GO TO 108
       IRG=I
       GO TO 109
108    CONTINUE
111    READ (TPE)
       GO TO 107
109    READ (TPE) DUMMA
       DO 114 IDA=D1,D2
  114 PE(IRG,IDA)=DUMMA(IDA)*25.4
107    CONTINUE
C SIX HOUR SNOW DATA
110    IF (SNOW.EQ.0) GO TO 120
       IF (MOIN.NE.10) GO TO 118
       IF ((YRIN.EQ.YR1).AND.(MOIN.EQ.MO1)) GO TO 118
       READ 900,SNOWA
  118 CALL SNOWIN(TTA,TAIN,D1,D2)
C OBSERVED FLOW DATA
C MEAN DAILY FLOW
  120 IF (NPTSIN.LT.1) GO TO 127
       DO 121 IG=1,NPTSIN
       DO 122 I=1,NPTS
       IF (SGIN(I).NE.IG) GO TO 122
       IPT=I
       GO TO 123
122    CONTINUE
       READ (TFW24)
       GO TO 121
123    READ (TFW24) DUMMA
       DO 126 IDA=D1,D2
  126 OFW24(IPT,IDA)=DUMMA(IDA)*0.0283168
121    CONTINUE
C SIX HOUR FLOW
127    IF (FW6IN.EQ.0) GO TO 145
       DO 141 IG=1,FW6IN
       DO 142 I=1,NPTS
       IF (SIXIN(I).NE.IG) GO TO 142
       IPT=I
       GO TO 143
```

```
142   CONTINUE
      READ (TFW6)
      GO TO 141
143   READ (TFW6)DUMMY
      DO 144 IDA=D1,D2
      DO 144 I6=1,4
  144 OFW6(IPT,IDA,I6)=DUMMY(I6,IDA)*0.0283168
141   CONTINUE
C UPSTREAM INFLOWS TO AREA
145    IF (UPFWIN.EQ.0) GO TO 155
      DO 151 IG=1,UPFWIN
      NN=TPTS-NPTS
      DO 152 I=1,NN
      IF (TPTIN(I).NE.IG) GO TO 152
      IPT=I
      GO TO 153
152   CONTINUE
      READ (TUPFW)
      GO TO 151
153   READ (TUPFW) DUMMY
      DO 154 IDA=D1,D2
      DO 154 I6=1,4
  154 UFW6(IPT,IDA,I6)=DUMMY(I6,IDA)*0.0283168
151   CONTINUE
155   CONTINUE
C INTAPE FORMAT STATEMENTS
900   FORMAT (12I5)
      RETURN
      END
```

*PRT,S .LAND

```
MORRIS*TPF$(0).LAND
      SUBROUTINE LAND(ID1,IP1,ID2,IP2,MOSM,ICOUNT,IRG)
C     NWSRFS SOIL MOISTURE ACCOUNTING PROCEDURE
C     BASED ON SOIL MOISTURE ACCOUNTING IN THE SACRAMENTO MODEL
C     LAND VARIABLES
      REAL LZTWC,LZFPC,LZFSC,LZTWC1,LZFPC1,LZFSC1,LZTWM,LZFPM,LZFSM,LZPK
     1,LZSK
      DIMENSION MOSM(8,2),EPDIST(4)
C GENERAL PROGRAM VARIABLES
      INTEGER ROUTE,TRO,SNOW,SNOWA,YRIN,YR1,SGIN,TPTS,STORE,YEAR,PLT6HR,
     1SAVEFW,TSAVE,COMPAR,PTEST,PLOT,CTEST,      SIXIN,OBSER,STDA,STP6,
     2YR2,USGSID,STAT,PEG
      REAL INFRO
      COMMON/G/MONTH,MOIN,LAST,ROUTE,NGAGES,TRO,SNOW,SNOWA(12),YRIN,
     1NPEGS,YR1,NPTS,SGIN(3),TPTS,STORE,BASIN(20),YEAR,SSF(3,12),
     2SOF(3,12),PLT6HR,SAVEFW,DUMMY(4,31),TSAVE,COMPAR(3),PTEST,PLOT(3),
     3LINEP,INFRO(20),PLOTMX(3),CTEST,FSFLOW(3),USGSID(3),PEG(5),STAT,
     4YR2,AREA(6),SIXIN(3),OBSER(3),STDA(2,10),STP6(2,10),IYEAR1(3),IPT,
     5METRIC(3)
C  SOIL MOISTURE ACCOUNTING VARIABLES.
      COMMON/SOIL/BAL(5),PL(5,18),VL(5,6),SL(5,10),E(5,12,31)
C TIME SERIES IDENTIFICATIONS AND DESCRIPTIONS.
      COMMON/TSID/AID(5,3),ANAME(5,5),PEID(3,3),FPNAME(6,5)
C BASIC DATA ARRAYS
      COMMON/BD/PX(5,31,4),TA(5,31,4),PE(3,31),RO(5,31,4),OFW6(3,31,4),
     1SFW6(3,31,4),UFW6(3,31,4),OFW24(3,31)
C SNOW AND LAND COMMON BLOCK
      COMMON/SL/COVER(5,31),EFC(5),PXADJ(5)
      DATA EPDIST/0.0,0.33,0.67,0.0/
C*************************************************************************
      IPRINT=0
      IF((MONTH.EQ.MOSM(ICOUNT,1)).AND.(YEAR.EQ.MOSM(ICOUNT,2)))IPRINT=1
      IF(IPRINT.EQ.0) GO TO 200
      PRINT 900,MONTH,YEAR,(ANAME(IRG,I),I=1,5)
  900 FORMAT(1H1,33HSIX-HOUR SOIL MOISTURE OUTPUT FOR,1X,I2,1H/,I2,2X,5A
     14,20X,39HUNITS OF ALL QUANTITIES ARE MILLIMETERS)
      PRINT 902
  902 FORMAT(1H ,5X,19HPERC IS PERCOLATION,5X,31HBASEFW IS THE CHANNEL C
     1OMPONENT,5X,67HTOTAL-RO IS CHANNEL INFLOW MINUS ET FROM THE AREA D
     2EFINED BY SARVA.)
      PRINT 901
  901 FORMAT(1H ,3HDAY,1X,2HPD,2X,5HUZTWC,2X,5HUZFWC,2X,5HLZTWC,2X,5HLZF
     1SC,2X,5HLZFPC,2X,5HADIMC,4X,4HPERC,1X,7HIMPV-RO,2X,6HDIRECT,2X,6HS
     2UR-RO,1X,7HINTERFW,2X,6HBASEFW,1X,8HTOTAL-RO,1X,7HET-DEMD,1X,6HACT
     3-ET,2X,9HRAIN+MELT)
  200 SROT=0.0
      SIMPVT=0.0
      SRODT=0.0
      SROST=0.0
      SINTFT=0.0
      SGWFT=0.0
      SRECHT=0.0
      SETT=0.0
      SPRT=0.0
      SPET=0.0
C     INTIAL VALUES OF VARIABLES
      UZTWC=VL(IRG,1)
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      UZFWC=VL(IRG,2)
      LZTWC=VL(IRG,3)
      LZFPC=VL(IRG,5)
      LZFSC=VL(IRG,4)
      ADIMC=VL(IRG,6)
      UZTWCI=UZTWC
      UZFWCI=UZFWC
      LZTWCI=LZTWC
      LZFPCI=LZFPC
      LZFSCI=LZFSC
      ADIMCI=ADIMC
C     INITIAL VALUES OF PARAMETERS
      PPADJ=PL(IRG,1)
      PEADJ=PL(IRG,2)
      UZTWM=PL(IRG,3)
      UZFWM=PL(IRG,4)
      UZK=PL(IRG,5)
      ZPERC=PL(IRG,9)
      REXP=PL(IRG,10)
      PCTIM=PL(IRG,6)
      ADIMP=PL(IRG,7)
      SARVA=PL(IRG,8)
      LZTWM=PL(IRG,11)
      LZFPM=PL(IRG,13)
      LZFSM=PL(IRG,12)
      LZPK=PL(IRG,15)
      LZSK=PL(IRG,14)
      PFREE=PL(IRG,16)
      RSERV=PL(IRG,17)
      SIDE=PL(IRG,18)
      WATSF=SARVA
      SARRA=0.0
      IF(SARVA.LE.PCTIM) GO TO 201
      WATSF=PCTIM
      SARRA=SARVA-PCTIM
  201 IGPE=PEG(IRG)
      EFCT=EFC(IRG)
      SAVED=RSERV*(LZFPM+LZFSM)
      PAREA=1.0-PCTIM-ADIMP
      IP6=IP1
      IDA=ID1
      GO TO 204
C**********************************************************************
C     BEGINNING OF 6 HOUR AND DAY LOOP
  205 IF(IP6.NE.1) GO TO 210
  204 IF(IGPE.GT.0) GO TO 206
C     NO PE INPUT, THUS PE IS OBTAIN FROM MEAN SEASONAL CURVE.
      EP=E(IRG,MONTH,IDA)
      GO TO 207
C     DAILY PE TIME SERIES IS AVAILABLE
  206 EP=PE(IGPE,IDA)
      EP=EP*E(IRG,MONTH,IDA)
  207 EP=EP*PEADJ
      SPET=SPET+EP
      IF(SNOW.EQ.1) EP=EFCT*EP+(1.0-EFCT)*(1.0-COVER(IRG,IDA))*EP
  210 IF((SNOW.EQ.1).AND.(SNOWA(MONTH).EQ.1)) GO TO 219
      PX6=PX(IRG,IDA,IP6)*PPADJ
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      GO TO 215
C     IF SNOW IS BEING CONSIDERED, PXADJ HAS ALREADY BEEN APPLIED
  219 PX6=PX(IRG,IDA,IP6)
  215 SPRT=SPRT+PX6
C     PX6 IS THE SIX HOUR RAINFALL OR SNOW COVER OUTFLOW
C*************************************************************************
C     EDMND IS SIX-HOUR EVAPORATION DEMAND
      EDMND=EP*EPDIST(IP6)
      E1=EDMND*(UZTWC/UZTWM)
      RED=EDMND-E1
C     RED IS RESIDUAL EVAP DEMAND
      UZTWC=UZTWC-E1
      E2=0.0
      IF(UZTWC.GE.0.) GO TO 220
C     E1 CAN NOT EXCEED UZTWC
      E1=E1+UZTWC
      UZTWC=0.0
      RED=EDMND-E1
      IF(UZFWC.GE.RED) GO TO 221
C     E2 IS EVAP FROM UZFWC.
      E2=UZFWC
      UZFWC=0.0
      RED=RED-E2
      GO TO 225
  221 E2=RED
      UZFWC=UZFWC-E2
      RED=0.0
  220 IF((UZTWC/UZTWM).GE.(UZFWC/UZFWM)) GO TO 225
C     UPPER ZONE FREE WATER RATIO EXCEEDS UPPER ZONE
C     TENSION WATER RATIO, THUS TRANSFER FREE WATER TO TENSION
      UZRAT=(UZTWC+UZFWC)/(UZTWM+UZFWM)
      UZTWC=UZTWM*UZRAT
      UZFWC=UZFWM*UZRAT
C     COMPUTE ET FROM ADIMP AREA.-E5
  225 E5=E1+(RED+E2)*((ADIMC-E1-UZTWC)/(UZTWM+LZTWM))
C     COMPUTE ET FROM LZTWC (E3)
      E3=RED*(LZTWC/(UZTWM+LZTWM))
      LZTWC=LZTWC-E3
      IF(LZTWC.GE.0.0) GO TO 226
C     E3 CAN NOT EXCEED LZTWC
      E3=E3+LZTWC
      LZTWC=0.0
  226 RATLZT=LZTWC/LZTWM
      RATLZ=(LZTWC+LZFPC+LZFSC-SAVED)/(LZTWM+LZFPM+LZFSM-SAVED)
      IF(RATLZT.GE.RATLZ) GO TO 230
C     RESUPPLY LOWER ZONE TENSION WATER FROM LOWER
C     ZONE FREE WATER IF MORE WATER AVAILABLE THERE.
      DEL=(RATLZ-RATLZT)*LZTWM
C     TRANSFER FROM LZFSC TO LZTWC.
      LZTWC=LZTWC+DEL
      LZFSC=LZFSC-DEL
      IF(LZFSC.GE.0.0) GO TO 230
C     IF TRANSFER EXCEEDS LZFSC THEN REMAINDER COMES FROM LZFPC
      LZFPC=LZFPC+LZFSC
      LZFSC=0.0
  230 ROIMP=PX6*PCTIM
C      ROIMP IS RUNOFF FROM THE MINIMUM IMPERVIOUS AREA.
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      SIMPVT=SIMPVT+ROIMP
C      ADJUST ADIMC,ADDITIONAL IMPERVIOUS AREA STORAGE, FOR EVAPORATION.
      ADIMC=ADIMC-E5
      IF(ADIMC.GE.0.0) GO TO 231
C     E5 CAN NOT EXCEED ADIMC.
      E5=E5+ADIMC
      ADIMC=0.0
  231 E5=E5*ADIMP
C     E5 IS ET FROM THE AREA ADIMP.
      PAV=PX6+UZTWC-UZTWM
C     PAV IS THE PERIOD AVAILABLE MOISTURE IN EXCESS
C     OF UZTW REQUIREMENTS.
      IF(PAV.GE.0.0) GO TO 232
C     ALL MOISTURE HELD IN UZTW--NO EXCESS.
      UZTWC=UZTWC+PX6
      PAV=0.0
      GO TO 233
C      MOISTURE AVAILABLE IN EXCESS OF UZTW STORAGE.
  232 UZTWC=UZTWM
  233 ADIMC=ADIMC+PX5-PAV
C*******************************************************************************
      SBF=0.0
      SSUR=0.0
      SIF=0.0
      SPERC=0.0
      SDRO=0.0
      NINC=1.0+0.2*(UZFWC+PAV)
C     NINC=NUMBER OF TIME INCREMENTS THAT THE SIX
C     HOUR PERIOD IS DIVIDED INTO FOR FURTHER
C     SOIL-MOISTURE ACCOUNTING.  NO ONE PERIOD
C     WILL EXCEED 5.0 MILLIMETERS OF UZFWC+PAV
      DINC=(1.0/NINC)*0.25
C     DINC=LENGTH OF EACH INCREMENT IN DAYS.
      PINC=PAV/NINC
C     PINC=AMOUNT OF AVAILABLE MOISTURE FOR EACH INCREMENT.
C      COMPUTE FREE WATER DEPLETION FRACTIONS FOR
C     THE TIME INTERVAL BEING USED-BASIC DEPLETIONS
C      ARE FOR ONE DAY
      DUZ=1.0-((1.0-UZK)**DINC)
      DLZP=1.0-((1.0-LZPK)**DINC)
      DLZS=1.0-((1.0-LZSK)**DINC)
      DO 240 IC=1,NINC
      PAV=PINC
      ADSUR=0.0
      RATIO=(ADIMC-UZTWC)/LZTWM
      ADDRO=PINC*(RATIO**2)
      SDRO=SDRO+ADDRO*ADIMP
C     ADDRO IS THE AMOUNT OF DIRECT RUNOFF FROM
C     THE AREA ADIMP-SDRO IS THE SIX HOUR SUMMATION
C     COMPUTE BASEFLOW AND KEEP TRACK OF SIX-HOUR SUM.
      BF=LZFPC*DLZP
      LZFPC=LZFPC-BF
      IF (LZFPC.GT.0.0001) GO TO 234
      BF=BF+LZFPC
      LZFPC=0.0
  234 SBF=SBF+BF
      BF=LZFSC*DLZS
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      LZFSC=LZFSC-BF
      IF(LZFSC.GT.0.0001) GO TO 235
      BF=BF+LZFSC
      LZFSC=0.0
  235 SBF=SBF+BF
C      COMPUTE PERCOLATION-IF NO WATER AVAILABLE THEN SKIP
      IF((PINC+UZFWC).GT.0.01) GO TO 251
      UZFWC=UZFWC+PINC
      GO TO 249
  251 PERCM=LZFPM*DLZP+LZFSM*DLZS
      PERC=PERCM*(UZFWC/UZFWM)
      DEFR=1.0-((LZTWC+LZFPC+LZFSC)/(LZTWM+LZFPM+LZFSM))
C     DEFR IS THE LOWER ZONE MOISTURE DEFICIENCY RATIO
      PERC=PERC*(1.0+ZPERC*(DEFR**REXP))
C     NOTE...PERCOLATION OCCURS FROM UZFWC BEFORE PAV IS ADDED.
      IF(PERC.LT.UZFWC) GO TO 241
C      PERCOLATION RATE EXCEEDS UZFWC.
      PERC=UZFWC
C     PERCOLATION RATE IS LESS THAT UZFWC.
  241 UZFWC=UZFWC-PERC
C     CHECK TO SEE IF PERCOLATION EXCEEDS LOWER ZONE DEFICIENCY.
      CHECK=LZTWC+LZFPC+LZFSC+PERC-LZTWM-LZFPM-LZFSM
      IF(CHECK.LE.0.0) GO TO 242
      PERC=PERC-CHECK
      UZFWC=UZFWC+CHECK
  242 SPERC=SPERC+PERC
C     SPERC IS THE SIX HOUR SUMMATION OF PERC
C     COMPUTE INTERFLOW AND KEEP TRACK OF SIX HOUR SUM.
C     NOTE...PAV HAS NOT YET BEEN ADDED.
      DEL=UZFWC*DUZ
      SIF=SIF+DEL
      UZFWC=UZFWC-DEL
C     DISTRIBE PERCOLATED WATER INTO THE LOWER ZONES
C     TENSION WATER MUST BE FILLED FIRST EXCEPT FOR THE PFREE AREA.
      VPERC=PERC
      PERC=PERC*(1.0-PFREE)
      IF((PERC+LZTWC).GT.LZTWM) GO TO 243
      LZTWC=LZTWC+PERC
      PERC=0.0
      GO TO 244
  243 PERC=PERC+LZTWC-LZTWM
      LZTWC=LZTWM
C      DISTRIBUTE PERCOLATION IN EXCESS OF TENSION
C      REQUIREMENTS AMONG THE FREE WATER STORAGES.
  244 PERC=PERC+VPERC*PFREE
      IF(PERC.EQ.0.0) GO TO 245
      HPL=LZFPM/(LZFPM+LZFSM)
C     HRL IS THE RELATIVE SIZE OF THE PRIMARY STORAGE
C     AS COMPARED WITH TOTAL LOWER ZONE FREE WATER STORAGE.
      RATLP=LZFPC/LZFPM
      RATLS=LZFSC/LZFSM
C     RATLP AND RATLS ARE CONTENT TO CAPACITY RATIOS, OR
C     IN OTHER WORDS, THE RELATIVE FULLNESS OF EACH STORAGE
      PERCP=PERC*((HPL*2.0*(1.0-RATLP))/((1.0-RATLP)+(1.0-RATLS)))
      PERCS=PERC-PERCP
C     PERCP AND PERCS ARE THE AMOUNT OF THE EXCESS
C     PERCOLATION GOING TO PRIMARY AND SUPPLEMENTAL
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C      STORGES,RESPECTIVELY.
      LZFSC=LZFSC+PERCS
      IF(LZFSC.LE.LZFSM) GO TO 246
      PERCS=PERCS-LZFSC+LZFSM
      LZFSC=LZFSM
  246 LZFPC=LZFPC+(PERC-PERCS)
C      DISTRIBUTE PAV BETWEEN UZFWC AND SURFACE RUNOFF.
  245 IF(PAV.EQ.0.0) GO TO 249
C     CHECK IF PAV EXCEEDS UZFWM
      IF((PAV+UZFWC).GT.UZFWM) GO TO 248
C     NO SURFACE RUNOFF
      UZFWC=UZFWC+PAV
      GO TO 249
C     COMPUTE SURFACE RUNOFF AND KEEP TRACK OF SIX HOUR SUM
  248 PAV=PAV+UZFWC-UZFWM
      UZFWC=UZFWM
      SSUR=SSUR+PAV*PAREA
      ADSUR=PAV*(1.0-ADDRO/PINC)
C     ADSUR IS THE AMOUNT OF SURFACE RUNOFF WHICH COMES
C     FROM THAT PORTION OF ADIMP WHICH IS NOT
C     CURRENTLY GENERATING DIRECT RUNOFF.  ADDRO/PINC
C     IS THE FRACTION OF ADIMP CURRENTLY GENERATING
C     DIRECT RUNOFF.
      SSUR=SSUR+ADSUR*ADIMP
  249 ADIMC=ADIMC+PINC-ADDRO-ADSUR
  240 CONTINUE
C     END OF INCREMENTAL DO LOOP.
C***********************************************************************
C     COMPUTE SUMS AND ADJUST RUNOFF AMOUNTS BY THE AREA OVER
C     WHICH THEY ARE GENERATED.
      EUSED=E1+E2+E3
C     EUSED IS THE ET FROM PAREA WHICH IS 1.0-ADIMP-PCTIM
      SIF=SIF*PAREA
C     SEPARATE CHANNEL COMPONENT OF BASEFLOW
C     FROM THE NON-CHANNEL COMPONENT
      TBF=SBF*PAREA
C     TBF IS TOTAL BASEFLOW
      BFCC=TBF*(1.0/(1.0+SIDE))
C     BFCC IS BASEFLOW, CHANNEL COMPONENT
      BFNCC=TBF-BFCC
C     BFNCC IS BASEFLOW,NON-CHANNEL COMPONENT
C     ADD TO MONTHLY SUMS.
      SINTFT=SINTFT+SIF
      SGWFT=SGWFT+BFCC
      SRECHT=SRECHT+BFNCC
      SROST=SROST+SSUR
      SRODT=SRODT+SDRO
C     COMPUTE TOTAL CHANNEL INFLOW FOR THE SIX-HOUR PERIOD.
      TCI=ROIMP+SDRO+SSUR+SIF+BFCC
C     COMPUTE E4-ET FROM STREAM SURFACES AND RIPARIAN VEGETATION.
      E4=EDMND*WATSF+(EDMND-EUSED)*SARRA
C     SUBTRACT E4 FROM CHANNEL INFLOW
      TCI=TCI-E4
      IF(TCI.GE.0.0) GO TO 250
      E4=E4+TCI
      TCI=0.0
C     COMPUTE TOTAL EVAPOTRANSPIRATION-TET
```

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      250 EUSED=EUSED*PAREA
          TET=EUSED+E5+E4
          SETT=SETT+TET
          RO(IRG,IDA,IP6)=TCI
          SROT=SROT+TCI
C          PRINT SIX-HOUR ACCOUNTING VALUES IF REQUESTED.
          IF(IPRINT.EQ.1) PRINT 903,IDA,IP6,UZTWC,UZFWC,LZTWC,LZFSC,LZFPC,AD
         1IMC,SPERC,ROIMP,SDRO,SSUR,SIF,BFCC,TCI,EDMND,TET,PX6
      903 FORMAT(1H ,2I3,6F7.1,7F8.2,3F8.1)
          IF((IDA.EQ.ID2).AND.(IP6.EQ.IP2)) GO TO 270
          IP6=IP6+1
          IF(IP6.LE.4) GO TO 205
          IP6=1
          IDA=IDA+1
          GO TO 205
C          END OF SIX HOUR AND DAY LOOP
C**********************************************************************
      270 IF(IRG.NE.NGAGES) GO TO 271
          IF((IPRINT.EQ.1).AND.(ICOUNT.LT.8)) ICOUNT=ICOUNT+1
      271 IPRINT=0
C         COMPUTE MONTHLY WATER BALANCE FOR AREAL SOIL MOISTURE ACCOUNTING.
          BAL(IRG)=(UZTWC+UZFWC+LZTWC+LZFPC+LZFSC-UZTWC1-UZFWC1-LZTWC1-LZFPC
         11-LZFSC1)*PAREA+(ADIMC-ADIMC1)*ADIMP+SROT+SRECHT+SETT-SPRT
          SL(IRG,1)=SROT
          SL(IRG,2)=SIMPVT
          SL(IRG,3)=SRODT
          SL(IRG,4)=SROST
          SL(IRG,5)=SINTFT
          SL(IRG,6)=SGWFT
          SL(IRG,7)=SRECHT
          SL(IRG,8)=SPRT
          SL(IRG,9)=SPET
          SL(IRG,10)=SETT
          VL(IRG,1)=UZTWC
          VL(IRG,2)=UZFWC
          VL(IRG,3)=LZTWC
          VL(IRG,5)=LZFPC
          VL(IRG,4)=LZFSC
          VL(IRG,6)=ADIMC
          RETURN
          END
```

@PRT,S .CHANEL

```
MORRIS*TPF$(0).CHANEL
      SUBROUTINE CHANEL (LDA1,LP61,LDA2,LP62)
C SUBROUTINE VARIABLES
      INTEGER ZT
      REAL LOCAL
      LOGICAL MIDOK,IDONE ,SMDPOS
      DIMENSION LOCAL(42),TRANS(42),TLAG(42)
C GENERAL PROGRAM VARIABLES
      INTEGER ROUTE,TRO,SNOW,SNOWA,YRIN,YR1,SGIN,TPTS,STORE,YEAR,PLT6HR,
     1SAVEFW,TSAVE,COMPAR,PTEST,PLOT,CTEST,      SIXIN,OBSER,STDA,STP6,
     2YR2,USGSID,STAT,PEG
      REAL INFRO
      COMMON/G/MONTH,MOIN,LAST,ROUTE,NGAGES,TRO,SNOW,SNOWA(12),YRIN,
     1NPEGS,YR1,NPTS,SGIN(3),TPTS,STORE,BASIN(20),YEAR,SSF(3,12),
     2SOF(3,12),PLT6HR,SAVEFW,DUMMY(4,31),TSAVE,COMPAR(3),PTEST,PLOT(3),
     3LINEP,INFRO(20),PLOTMX(3),CTEST,FSFLOW(3),USGSID(3),PEG(5),STAT,
     4YR2,AREA(6),SIXIN(3),OBSER(3),STDA(2,10),STP6(2,10),IYEAR1(3),IPT,
     5METRIC(3)
C MAIN AND CHANEL VARIABLES
      INTEGER VARK,VARL,RINT,Z,GAGEAR
      REAL KS1,KS2,KINCRE,KS2V,LINCRE,LOCALI,INFLOL,LAG
      COMMON/CHAN/FWP4I(3),KS1(3),KS2(3),VARK(3),VARL(3),
     1RINT(3),Z(3),NUPIN(3),KINCRE(3,10),KS2V(3,11),LINCRE(3,10),LAG
     2(3,10),TDELAY(3,30),GAGEAR(3,30),IFLOPT(3,3),UPLAG(3,3),CFSM(3),
     3PREVI1(3),LOCALI(3,42),TLAGI(3,42),TRANSI(3,42),MAXL(3),TLAGLI(3),
     4INFLOL(3,10),OTFLOK(3,11),NKPTS(3),NLPTS(3),PREVI2(3),SSOUT(3)
C BASIC DATA ARRAYS
      COMMON/BD/PX(5,31,4),TA(5,31,4),PE(3,31),RO(5,31,4),OFW6(3,31,4),
     1SFW6(3,31,4),UFW6(3,31,4),OFW24(3,31)
C
C ********NOTE***********NOTE***********NOTE*********NOTE**********
C             THE TIME-DELAY HISTOGRAM IS THE SIX-HOUR TIME-DELAY HISTOGRAM
C                   AND GIVES AVERAGE INFLOW FOR THE PERIOD.
C             PREVIOUS OUTFLOW , AVERAGE INFLOWS FOR THE PERIOD AND THE PROPER K
C                   WILL GIVE INSTANTANEOUS OUTFLOW AT THE END OF THE PERIOD
C ********NOTE***********NOTE***********NOTE*********NOTE**********
C
C     CALLING SEQUENCE -LDA1,LP61 GIVE FIRST DAY, PERIOD FOR WHICH
C                             FLOW IS TO BE SIMULATED
C                       LDA2, LP62 GIVE LAST DAY, PERIOD FOR WHICH
C                             FLOW IS TO BE SIMULATED
C
      RINTT=RINT(IPT)
      CLOSS=SSOUT(IPT)
      ZT=Z(IPT)
      MAXLT=MAXL(IPT)
      MAXCO=MAXLT+2
      NUPINT=NUPIN(IPT)
      IF (VARK(IPT).NE.0) GO TO 110
      ROTK=KS1(IPT)
      DNM=2.0*ROTK+RINTT
      FOUTN=(2.0*ROTK-RINTT)/DNM
      FINBAR=2.0*RINTT/DNM
110   PREVF=PREVI1 (IPT)
      PREVLF=PREVI2(IPT)
      TLAGL=TLAGLI (IPT)
      FWP4=FWP4I(IPT)
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      DO 142 I=1,MAXCO
      LOCAL (I)=LOCALI (IPT,I)
      TRANS (I)=TRANSI (IPT,I)
  142 TLAG (I)=TLAGI (IPT,I)
      LDA=LDAI
      LP6=LP6I
      LPER=1
C           *************
C           BEGIN ROUTE
C
C             **FIRST GET LOCAL,ADD TO LAGGED LOCAL FLOW FROM PREVIOUS
  165 DO 10 I=1,ZT
      LIRG=GAGEAR (IPT,I)
   10 LOCAL (I)=LOCAL (I)+RO(LIRG,LDA,LP6)*TDELAY(IPT,I)*CFSM(IPT)
      TRANS(I)=TRANS(I)+LOCAL(I)
C         **NOW LAG UPSTREAM INFLOWS
      IF (NUPIN (IPT).EQ.0) GO TO 30
      DO 17 IN=1,NUPINT
C            NUPIN=NUMBER OF UPSTREAM INFLOWS
      IFPT=IFLOPT (IPT,IN)
C            IFPT=FLOWPOINT NUMBER OF THE (IN)TH UPSTREAM INFLOW
      IF (IFPT.GT.NPTS) GO TO 3015
      IF (OBSER(IFPT).EQ.0) GO TO 1015
      GO TO 2015
 1015 UPFLO=SFW6(IFPT,LDA,LP6)
      GO TO 12
 2015 UPFLO=OFW6(IFPT,LDA,LP6)
      GO TO 12
 3015 NUP=IFPT-NPTS
      UPFLO=UFW6(NUP,LDA,LP6)
   12 J=(UPLAG(IPT,IN)+9.01)/6.0
C            J IS THE EARLIEST SIX HOUR PERIOD IN WHICH THE PRESENT
C            FLOW AT THE (IN)TH INFLOW WILL CONTRIBUTE AT IPT
      RINTJ=6*J-3
      FRTOJ=(RINTJ-UPLAG(IPT,IN))/6.0
      TRANS(J+1)=TRANS(J+1)+UPFLO*(1.0-FRTOJ)
      TRANS(J)=TRANS(J)+UPFLO*FRTOJ
   17 CONTINUE
C          **DONE UPSTREAM INFLOW LAG. NOW VARIABLE IF ANY.
   30 IF (VARL(IPT).NE.0) GO TO 31
      TLAG(I)=TRANS(I)
      GO TO 50
   31 IDONE=.FALSE.
      DO 45 I=1,10
      IF (TRANS(I).GT.INFLOL(IPT,I)) GO TO 40
      IDONE=.TRUE.
      VOLINC=TRANS(I)-INFLOL(IPT,I)+LINCRE(IPT,I)
      GO TO 41
   40 VOLINC=LINCRE(IPT,I)
   41 FLAGV=LAG(IPT,I)
C           FLAGV IS THE ADDED LAG TO BE APPLIED TO THE
C           VOLUME INCREMENT VOLINC
  411 J=(FLAGV+6.01)/6.0
C     J IS THE EARLIEST SIX HOUR PERIOD IN WHICH VOLINC WILL CONTRIBUTE
   43 RINTJ=6*J
      FRTOJ=(RINTJ-FLAGV)/6.0
C           FRTOJ IS THE FRACTION OF VOLINC GOING TO THE (J)TH
```

```
C           ELEMENT OF THE VARIABLY LAGGED HYDROGRAPH
      TLAG (J+1)=TLAG(J+1)+VOLINC*(1.0-FRTOJ)
   44 TLAG(J)=TLAG(J)+VOLINC*FRTOJ
      IF(IDONE) GO TO 50
   45 CONTINUE
C            **NOW HAVE LAGGED FLOW (VARIABLY OR CONSTANT). NOW APPLY K.
   50 IF(VARK(IPT).EQ.0.AND.NUPIN(IPT).EQ.0)  GO TO 53
      IF(VARK(IPT).EQ.0)  GO TO 54
      DO 52 KVL=2,11
      IF (PREVF.GT.OTFLOK(IPT,KVL)) GO TO 51
      KVLM=KVL-1
      ROTK=KS2V(IPT,KVLM)+KINCRE(IPT,KVLM)*(PREVF-OTFLOK(IPT,KVLM))
      DNM=2.0*ROTK+RINTT
      FOUTN=(2.0*ROTK-RINTT)/DNM
      FINBAR=2.0*RINTT/DNM
      GO TO 53
   51 CONTINUE
   52 CONTINUE
   54 ROTK=KS2(IPT)
      DNM=2.0*ROTK+RINTT
      FOUTN=(2.0*ROTK-RINTT)/DNM
      FINBAR=2.0*RINTT/DNM
      TLAG(1)=TLAG(1)-LOCAL(1)
   53 SFW6(IPT,LDA,LP6)=(FOUTN*PREVF+FINBAR*TLAG(1))
      SFW6(IPT,LDA,LP6)=SFW6(IPT,LDA,LP6)-CLOSS
C
C           ** DONE. NOW UPDATE CARRY ARRAYS
C
      PREVF=SFW6 (IPT,LDA,LP6)
      IF(PREVF.LT.0.001) PREVF=0.0
      IF(PREVLF.LT.0.001)  PREVLF=0.0
      IF(NUPIN(IPT).EQ.0)  GO TO 55
      ROTK=KS1(IPT)
      DNM=2.0*ROTK+RINTT
      FOUTN=(2.0*ROTK-RINTT)/DNM
      FINBAR=2.0*RINTT/DNM
      LOCAL(1)=FOUTN*PREVLF+FINBAR*LOCAL(1)
      PREVLF=LOCAL(1)
C     SUBTRACT CONSTANT CHANNEL LOSS
      SFW6(IPT,LDA,LP6)=SFW6(IPT,LDA,LP6)+LOCAL(1)
   55 TLAGL=TLAG(1)
      IF (SFW6(IPT,LDA,LP6).LT.0.0)SFW6(IPT,LDA,LP6)=0.0
      TLAGL=TLAG(1)
      MXLM=MAXCO-1
      DO 60 I=1,MXLM
      TLAG(I)=TLAG(I+1)
      TRANS(I)=TRANS(I+1)
   60 LOCAL(I)=LOCAL(I+1)
      TLAG(MAXCO)=0.0
      TRANS(MAXCO)=0.0
      LOCAL(MAXCO)=0.0
C            END ROUTE
C            *********
C
      IF (LDA.EQ.LDA2) GO TO 185
      IF (LP6.NE.4) GO TO 186
      LDA=LDA+1
```

```
      LP6=1
      GO TO 187
  185 IF (LP6.EQ.LP62) GO TO 190
  186 LP6=LP6+1
  187 LPER=LPER+1
      GO TO 165
C     ************************************************
C      **FOLLOWING 300 SERIES CODING PUTS BEST KNOWN VALUES INTO
C      **OBSERVED SIX HOUR FLOW ARRAY.(OBSER(IPT)=1)
190   IF(OBSER(IPT).NE.1) GO TO 2190
      MIDOK=.TRUE.
      LDA=LDA1
      LP6=LP61
      LSD=LDA-1
320   IF (SIXIN(IPT).EQ.0) GO TO 326
      IF  (OFW6(IPT,LDA,LP6).LT.0.0) GO TO 326
      IF (MIDOK) GO TO 360
      IF(SMDPOS) GO TO 322
      OFW6(IPT,LDAMID,LP6MID)=OFW24(IPT,LDAMID)
      GO TO 323
  322 OFW6(IPT,LDAMID,LP6MID)=RAT*SFW6(IPT,LDAMID,LP6MID)
  323 MIDOK=.TRUE.
      GO TO 360
326   IF (COMPAR(IPT).EQ.1) GO TO 340
  338 OFW6(IPT,LDA,LP6)=SFW6(IPT,LDA,LP6)
      GO TO 360
340   IF (OFW24(IPT,LDA).LT.0.0) GO TO 338
      IF (LP6.EQ.1) GO TO 348
      IF (LSD.EQ.LDA) GO TO 355
  348 SMDPOS=.TRUE.
      IF (LDA.EQ.LDA1) GO TO 349
      LDM=LDA-1
      SMDF=SFW6(IPT,LDM,4)
      GO TO 350
  349 SMDF=FWP4
  350 SMDF=(SMDF+2.0*(SFW6(IPT,LDA,1)+SFW6(IPT,LDA,2)+SFW6(IPT,LDA,3))+
     1 SFW6(IPT,LDA,4))/8.0
      RATP=RAT
      IF (SMDF.GT.0.0005) GO TO 351
      SMDPOS=.FALSE.
      RAT=-1.
      GO TO 352
  351 RAT=OFW24(IPT,LDA)/SMDF
  352 LSD=LDA
      IF(MIDOK) GO TO 355
      IF(RATP.GE.0.) GO TO 1352
      OFW6(IPT,LDAMID,LP6MID)=OFW24(IPT,LDAMID)
      GO TO 354
 1352 IF (SMDPOS) GO TO 353
      OFW6(IPT,LDAMID,LP6MID)=OFW24(IPT,LDAMID)
      GO TO 354
  353 OFW6(IPT,LDAMID,LP6MID)=SFW6(IPT,LDAMID,LP6MID)*(RAT+RATP)/2.0
  354 MIDOK=.TRUE.
  355 IF(LP6.NE.4) GO TO 358
      IF(LDA.EQ.LDA2) GO TO 358
      LDAMID=LDA
      LP6MID=LP6
```

```
      MIDOK=.FALSE.
      GO TO 360
  358 IF(SMDPOS) GO TO 359
      OFW6(IPT,LDA,LP6)=OFW24(IPT,LDA)
      GO TO 360
  359 OFW6(IPT,LDA,LP6)=RAT*SFW6(IPT,LDA,LP6)
  360 IF (LDA.EQ.LDA2) GO TO 362
      IF (LP6.NE.4) GO TO 366
      LDA=LDA+1
      LP6=1
      GO TO 320
  362 IF (LP6.EQ.LP62) GO TO 2190
  366 LP6=LP6+1
      GO TO 320
C     ***********************************************************
 2190 PREVI1(IPT)=PREVF
      PREVI2(IPT)=PREVLF
      TLAGLI(IPT)=TLAGL
      DO 191 I=1,MAXCO
      TRANSI(IPT,I)=TRANS(I)
      TLAGI(IPT,I)=TLAG(I)
  191 LOCALI(IPT,I)=LOCAL(I)
  199 RETURN
      END

@PRT,S  .LANDOT
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MORRIS*TPF$(0).LANDOT

```
      SUBROUTINE LANDOT
C OUTPUT SUMMARY FOR NON-FORECAST MODE--LAND PHASE
C GENERAL PROGRAM VARIABLES
      INTEGER ROUTE,TRO,SNOW,SNOWA,YRIN,YRI,SGIN,TPTS,STORE,YEAR,PLT6HR,
     1SAVEFW,TSAVE,COMPAR,PTEST,PLOT,CTEST,      SIXIN,OBSER,STDA,STP6,
     2YR2,USGSID,STAT,PEG
      REAL INFRO
      COMMON/G/MONTH,MOIN,LAST,ROUTE,NGAGES,TRO,SNOW,SNOWA(12),YRIN,
     1NPEGS,YRI,NPTS,SGIN(3),TPTS,STORE,BASIN(20),YEAR,SSF(3,12),
     2SCF(3,12),PLT6HR,SAVEFW,DUMMY(4,31),TSAVE,COMPAR(3),PTEST,PLOT(3),
     3LINEP,INFRO(20),PLOTMX(3),CTEST,FSFLOW(3),USGSID(3),PEG(5),STAT,
     4YR2,AREA(6),SIXIN(3),OBSER(3),STDA(2,10),STP6(2,10),IYEARI(3),IPT,
     5METRIC(3)
C  SOIL MOISTURE ACCOUNTING VARIABLES.
      COMMON/SOIL/BAL(5),PL(5,18),VL(5,6),SL(5,10),E(5,12,31)
C BASIC DATA ARRAYS
      COMMON/BD/PX(5,31,4),TA(5,31,4),PE(3,31),RO(5,31,4),OFW6(3,31,4),
     1SFW6(3,31,4),UFW6(3,31,4),OFW24(3,31)
      COMMON/OUT/ISTOUT,ARMO(5,12,22)
      IF (STORE.EQ.0) GO TO 100
      DO 101 IRG=1,NGAGES
      DO 102 IDA=1,31
      DO 102 IP6=1,4
102   DUMMY(IP6,IDA)=RO(IRG,IDA,IP6)
      WRITE (TRO) DUMMY
101   CONTINUE
100   IF (ISTOUT.EQ.0) GO TO 107
C     STORE LAND STORAGES AND FLOW COMPONENTS FOR END OF YEAR PRINTOUT
      DO 105 IRG=1,NGAGES
      ARMO(IRG,MONTH,1)=SL(IRG,1)
      ARMO(IRG,MONTH,2)=SL(IRG,2)
      ARMO(IRG,MONTH,3)=SL(IRG,3)
      ARMO(IRG,MONTH,4)=SL(IRG,4)
      ARMO(IRG,MONTH,5)=SL(IRG,5)
      ARMO(IRG,MONTH,6)=SL(IRG,6)
      ARMO(IRG,MONTH,7)=SL(IRG,7)
      ARMO(IRG,MONTH,8)=SL(IRG,8)
      ARMO(IRG,MONTH,9)=SL(IRG,9)
      ARMO(IRG,MONTH,10)=SL(IRG,10)
      ARMO(IRG,MONTH,15)=VL(IRG,1)
      ARMO(IRG,MONTH,16)=VL(IRG,2)
      ARMO(IRG,MONTH,17)=VL(IRG,3)
      ARMO(IRG,MONTH,18)=VL(IRG,4)
      ARMO(IRG,MONTH,19)=VL(IRG,5)
C     SLZM IS TOTAL LOWER ZONE CAPACITY.
      SLZM=PL(IRG,11)+PL(IRG,12)+PL(IRG,13)
C     SLZC IS TOTAL LOWER ZONE CONTENTS.
      SLZC=VL(IRG,3)+VL(IRG,4)+VL(IRG,5)
      DEFR=1.0-(SLZC/SLZM)
      ARMO(IRG,MONTH,20)=DEFR
      ARMO(IRG,MONTH,21)=VL(IRG,6)
      ARMO(IRG,MONTH,22)=BAL(IRG)
  105 CONTINUE
107   CONTINUE
      RETURN
      END
```

```
MORRIS*TPF$(0).CHANOT
      SUBROUTINE CHANOT
C OUTPUT SUMMARY FOR NON-FORECAST MODE--CHANNEL
C CHANOT VARIABLES
      REAL MOCHAR(12),D(5,31)
C GENERAL PROGRAM VARIABLES
      INTEGER ROUTE,TRO,SNOW,SNOWA,YRIN,YRI,SGIN,TPTS,STORE,YEAR,PLT6HR,
     1SAVEFW,TSAVE,COMPAR,PTEST,PLOT,CTEST,      SIXIN,OBSER,STDA,STP6,
     2YR2,USGSID,STAT,PEG
      REAL  INFRO
      COMMON/G/MONTH,MOIN,LAST,ROUTE,NGAGES,TRO,SNOW,SNOWA(12),YRIN,
     1NPEGS,YRI,NPTS,SGIN(3),TPTS,STORE,BASIN(20),YEAR,SSF(3,12),
     2SOF(3,12),PLT6HR,SAVEFW,DUMMY(4,31),TSAVE,COMPAR(3),PTEST,PLOT(3),
     3LINEP,INFRO(20),PLOTMX(3),CTEST,FSFLOW(3),USGSID(3),PEG(5),STAT,
     4YR2,AREA(6),SIXIN(3),OBSER(3),STDA(2,10),STP6(2,10),IYEARI(3),IPT,
     5METRIC(3)
C MAIN AND CHANEL VARIABLES
      INTEGER VARK,VARL,RINT,Z,GAGEAR
      REAL KS1,KS2,KINCRE,KS2V,LINCRE,LOCALI,INFLOL,LAG
      COMMON/CHAN/FWP4I(3),KS1(3),KS2(3),VARK(3),VARL(3),
     1RINT(3),Z(3),NUPIN(3),KINCRE(3,10),KS2V(3,11),LINCRE(3,10),LAG
     2(3,10),TDELAY(3,30),GAGEAR(3,30),IFLOPT(3,3),UPLAG(3,3),CFSM(3),
     3PREVI1(3),LOCALI(3,42),TLAGI(3,42),TRANSI(3,42),MAXL(3),TLAGLI(3),
     4INFLOL(3,10),OTFLOK(3,11),NKPTS(3),NLPTS(3),PREVI2(3),SSOUT(3)
C BASIC DATA ARRAYS
      COMMON/BD/PX(5,31,4),TA(5,31,4),PE(3,31),RO(5,31,4),OFW6(3,31,4),
     1SFW6(3,31,4),UFW6(3,31,4),OFW24(3,31)
C DAILY PLOT DATA ARRAYS
      COMMON/PD/DPX(3,12,31),SFW24(3,12,31),WYFW24(3,12,31)
C SNOW AND LAND COMMON BLOCK
      COMMON/SL/COVER(5,31),EFC(5),PXADJ(5)
      DATA MOCHAR/3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,4HJUNE,4HJULY,3HAUG,
     14HSEPT,3HOCT,3HNOV,3HDEC/
C COMPUTE MEAN DAILY SIMULATED FLOW
      SUM=0.0
      FWI=FWP4I(IPT)
      DO 122 IDA=1,LAST
      TEMPOR=0.5*FWI+SFW6(IPT,IDA,1)+SFW6(IPT,IDA,2)+SFW6(IPT,IDA,3)+
     10.5*SFW6(IPT,IDA,4)
      FWI=SFW6(IPT,IDA,4)
      TEMPOR=TEMPOR/4.0
      SFW24(IPT,MONTH,IDA)=TEMPOR
  122 SUM=SUM+TEMPOR
      SSF(IPT,MONTH)=SUM
      FWP4I(IPT)=FWI
C COMPUTE MONTHLY SUM OF OBSERVED FLOW
      IF (COMPAR(IPT).EQ.0) GO TO 125
      SUM=0.0
      DO 126 IDA=1,LAST
      WYFW24(IPT,MONTH,IDA)=OFW24(IPT,IDA)
  126 SUM=SUM+OFW24(IPT,IDA)
      SOF(IPT,MONTH)=SUM
  125 CONTINUE
C     PLOT SIX HOUR SIMULATED VERSUS OBSERVED FLOW
      IF (PLT6HR.EQ.0) GO TO 140
      IF (SIXIN(IPT).EQ.0) GO TO 140
      DO 130 IC=1,10
```

```
      IF (STDA(1,IC).EQ.0) GO TO 140
      ID1=STDA(1,IC)
      IP1=STP6(1,IC)
      ID2=STDA(2,IC)
      IP2=STP6(2,IC)
      CALL FLOWOT (ID1,IP1,ID2,IP2)
130   CONTINUE
140   CONTINUE
C     COMPUTE PRECIP.AND/OR MELT FOR LOCAL AREA
C     ABOVE FLOW-POINT
      IF (ROUTE.EQ.1) GO TO 150
      IF (PTEST.EQ.0) GO TO 150
      IF (IPT.GT.1) GO TO 152
      DO 151 IRG=1,NGAGES
      AK1=PXADJ(IRG)
      IF((SNOW.EQ.1).AND.(SNOWA(MONTH).EQ.1)) AK1=1.0
      DO 151 IDA=1,LAST
      D(IRG,IDA)=0.0
      DO 151 IP6=1,4
      D(IRG,IDA)=D(IRG,IDA)+PX(IRG,IDA,IP6)*AK1
151   CONTINUE
152   IF (PLOT(IPT).EQ.0) GO TO 150
      IZ=Z(IPT)
      DO 153 IE=1,IZ
      IRG=GAGEAR(IPT,IE)
      X=TDELAY(IPT,IE)
      DO 153 IDA=1,LAST
      DPX(IPT,MONTH,IDA)=DPX(IPT,MONTH,IDA)+D(IRG,IDA)*X
153   CONTINUE
150   CONTINUE
      RETURN
      END
```

•PRT,S .FLOWOT

MORRIS*TPF$(0).FLOWOT

```
      SUBROUTINE FLOWOT(DA1,P61,DA2,P62)
C SIX HOUR FLOW PLOT
      INTEGER    DA,DA1,P61,DA2,P62
      DIMENSION SCALE(11),ORD(101),FS(248),FA(248),MOCHAR(12),UNITS(2)
C GENERAL PROGRAM VARIABLES
      INTEGER ROUTE,TRO,SNOW,SNOWA,YRIN,YR1,SGIN,TPTS,STORE,YEAR,PLT6HR,
     1SAVEFW,TSAVE,COMPAR,PTEST,PLOT,CTEST,      SIXIN,CBSER,STDA,STP6,
     2YR2,USGSID,STAT,PEG
      REAL  INFRO
      COMMON/G/MONTH,MOIN,LAST,ROUTE,NGAGES,TRO,SNOW,SNOWA(12),YRIN,
     1NPEGS,YR1,NPTS,SGIN(3),TPTS,STORE,BASIN(20),YEAR,SSF(3,12),
     2SOF(3,12),PLT6HR,SAVEFW,DUMMY(4,31),TSAVE,COMPAR(3),PTEST,PLOT(3),
     3LINEP,INFRO(20),PLOTMX(3),CTEST,FSFLOW(3),USGSID(3),PEG(5),STAT,
     4YR2,AREA(6),SIXIN(3),CBSER(3),STDA(2,10),STP6(2,10),IYEAR1(3),IPT,
     5METRIC(3)
C BASIC DATA ARRAYS
      COMMON/BD/PX(5,31,4),TA(5,31,4),PE(3,31),RO(5,31,4),OFW6(3,31,4),
     1SFW6(3,31,4),UFW6(3,31,4),OFW24(3,31)
C TIME SERIES IDENTIFICATIONS AND DESCRIPTIONS.
      COMMON/TSID/AID(5,3),ANAME(5,5),PEID(3,3),FPNAME(6,5)
      DATA MOCHAR/3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,4HJUNE,4HJULY,3HAUG,
     14HSEPT,3HOCT,3HNOV,3HDEC/
      DATA DOT,BLANK,ASTER,PLUS/1H.,1H ,1H*,1H+/
      DATA UNITS/3HFT.,3H M./
      IU=METRIC(IPT)+1
      PRINT 900,(FPNAME(IPT,I),I=1,5),MOCHAR(MONTH),YEAR,UNITS(IU)
      IU=IU-1
      IP1=(DA1-1)*4+P61
      IP2=(DA2-1)*4+P62
      FMAX=0.0
      DO 100 IP=IP1,IP2
      DA=(IP-1)/4+1
      I6=IP-(DA-1)*4
      IF (IU.EQ.0) GO TO 101
      FS(IP)=SFW6(IPT,DA,I6)
      FA(IP)=OFW6(IPT,DA,I6)
      GO TO 102
  101 FS(IP)=35.3147*SFW6(IPT,DA,I6)
      FA(IP)=35.3147*OFW6(IPT,DA,I6)
  102 IF (SIXIN(IPT).EQ.0)FA(IP)=-0.01
      IF (FS(IP).GT.FMAX) FMAX=FS(IP)
      IF (FA(IP).GT.FMAX) FMAX=FA(IP)
  100 CONTINUE
      DO 106 I=1,6
      X=10.0**I
      IF ((FMAX/X).LE.10.0) GO TO 107
      GO TO 106
  107 N=(FMAX/X)+1.0
      PMAX=N*X
      GO TO 109
  106 CONTINUE
  109 DO 110 I=1,11
      DEC=I-1
  110 SCALE(I)=DEC*0.1*PMAX
      PRINT 901,SCALE
      DO 120 IP=IP1,IP2
```

```
      DA=(IP-1)/4+1
      I6=IP-(DA-1)*4
      DO 121 I=1,101,10
      ORD(I)=DOT
      IF (I.EQ.101) GO TO 121
      DO 122 J=1,9
      ORD(I+J)=BLANK
122   CONTINUE
121   CONTINUE
      IF (IP.NE.IP2) GO TO 125
      DO 123 I=1,101
123   ORD(I)=DOT
125   LS=(FS(IP)/PMAX)*100.0+1.5
      LA=(FA(IP)/PMAX)*100.0+1.5
      IF (FA(IP).GE.0.0) ORD(LA)=PLUS
      ORD(LS)=ASTER
      IF (IU.EQ.0) GO TO 119
      PRINT 903,DA,I6,ORD,FS(IP),FA(IP)
      GO TO 120
  119 PRINT 902,DA,I6,ORD,FS(IP),FA(IP)
120   CONTINUE
C     FLOWOT FORMAT STATEMENTS
900   FORMAT (1H1,18HSIX HOUR FLOW PLOT,5X,5A4,5X,A4,3H,19,I2,5X,24H*=SI
     1MULATED    +=OBSERVED,5X,15HUNITS ARE CUBIC,1X,A3,5H/SEC.)
  901 FORMAT (1H ,4HTIME,F5.1,F9.1,9F10.1,1X,9HSIMULATED,2X,8HOBSERVED)
  902 FORMAT (1H ,I2,1H-,I1,1X,101A1,2X,2F10.1)
  903 FORMAT (1H ,I2,1H-,I1,1X,101A1,2X,2F10.3)
      RETURN
      END

@PRT,S  .SUMARY
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```
MORRIS*TPF$(0).SUMARY
      SUBROUTINE SUMARY(MDFTBL)
C     OUTPUT SUMMARY
C SUMARY VARIABLE
      REAL MOCHAR(12),SCM(12),OCM(12),DCM(12)
      DIMENSION SUM(13)
C GENERAL PROGRAM VARIABLES
      INTEGER ROUTE,TRO,SNOW,SNOWA,YRIN,YR1,SGIN,TPTS,STORE,YEAR,PLT6HR,
     1SAVEFW,TSAVE,COMPAR,PTEST,PLOT,CTEST,      SIXIN,OBSER,STDA,STP6,
     2YR2,USGSID,STAT,PEG
      REAL INFRO
      COMMON/G/MONTH,MOIN,LAST,ROUTE,NGAGES,TRO,SNOW,SNOWA(12),YRIN,
     1NPEGS,YR1,NPTS,SGIN(3),TPTS,STORE,BASIN(20),YEAR,SSF(3,12),
     2SOF(3,12),PLT6HR,SAVEFW,DUMMY(4,31),TSAVE,COMPAR(3),PTEST,PLOT(3),
     3LINEP,INFRO(20),PLOTMX(3),CTEST,FSFLOW(3),USGSID(3),PEG(5),STAT,
     4YR2,AREA(6),SIXIN(3),OBSER(3),STDA(2,10),STP6(2,10),IYEAR1(3),IPT,
     5METRIC(3)
C DAILY PLOT DATA ARRAYS
      COMMON/PD/DPX(3,12,31),SFW24(3,12,31),WYFW24(3,12,31)
C TIME SERIES IDENTIFICATIONS AND DESCRIPTIONS.
      COMMON/TSID/AID(5,3),ANAME(5,5),PEID(3,3),FPNAME(6,5)
      COMMON/OUT/ISTOUT,ARMO(5,12,22)
      DATA MOCHAR/3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,4HJUNE,4HJULY,3HAUG,
     14HSEPT,3HOCT,3HNOV,3HDEC/
C     MONTHLY SUMMARY TABLES
      IF (ISTOUT.EQ.0) GO TO 140
      DO 131 IRG=1,NGAGES
      PRINT 900
      IWY=YEAR
      IF (MONTH.GT.9)IWY=YEAR+1
      PRINT 901,IRG,(ANAME(IRG,I),I=1,5),IWY
      PRINT 903
      PRINT 914
      PRINT 904
      DO 132 I=1,13
  132 SUM(I)=0.0
      DO 133 MO=10,12
      DO 134 I=1,13
  134 SUM(I)=SUM(I)+ARMO(IRG,MO,I)
      PRINT 905,MOCHAR(MO),(ARMO(IRG,MO,I),I=1,10)
  133 CONTINUE
      DO 135 MO=1,9
      DO 136 I=1,13
  136 SUM(I)=SUM(I)+ARMO(IRG,MO,I)
      PRINT 905,MOCHAR(MO),(ARMO(IRG,MO,I),I=1,10)
  135 CONTINUE
      PRINT 906,(SUM(I),I=1,10)
      PRINT 919
      PRINT 907
      IF (SNOW.EQ.1) PRINT 908
      PRINT 909
      IF (SNOW.EQ.1) PRINT 910
      DO 137 MO=10,12
      PRINT 911,MOCHAR(MO),(ARMO(IRG,MO,I),I=15,22)
      IF (SNOW.EQ.1)PRINT 912,(ARMO(IRG,MO,I),I=11,14)
  137 CONTINUE
      DO 138 MO=1,9
```

```
      PRINT 911,MOCHAR(MO),(ARMO(IRG,MO,I),I=15,22)
      IF (SNOW.EQ.1) PRINT 912,(ARMO(IRG,MO,I),I=11,14)
  138 CONTINUE
      IF (SNOW.EQ.1) PRINT 913,(SUM(I),I=11,13)
      PRINT 929
  131 CONTINUE
      DO 139 IRG=1,NGAGES
      DO 139 MO=1,12
      DO 139 I=1,22
  139 ARMO(IRG,MO,I)=0.0
  140 CONTINUE
C WATER YEAR SIMULATED FLOW SUMMARY TABLES
      LEAPYR=0
      IF ((YEAR-4*(YEAR/4)).EQ.0) LEAPYR=1
      IF (MDFTBL.EQ.0) GO TO 149
      DO 141 IPT=1,NPTS
      PRINT 915,(FFNAME(IPT,I),I=1,5)
      IYR=YEAR
      IF (MONTH.GT.9) IYR=IYR+1
      PRINT 916,IYR
      PRINT 917
      PRINT 918
      PRINT 919
      N=28
      IF (LEAPYR.EQ.1) N=29
      DO 142 IDA=1,N
      PRINT 920,IDA,(SFW24(IPT,MO,IDA),MO=10,12),(SFW24(IPT,MO,IDA),
     1MO=1,9)
      IF((IDA-5*(IDA/5)) .EQ. 0) PRINT 921
142   CONTINUE
      N=N+1
      DO 143 IDA=N,30
      PRINT 922,IDA,(SFW24(IPT,MO,IDA),MO=10,12),
     1SFW24(IPT,1,IDA),(SFW24(IPT,MO,IDA),MO=3,9)
143   CONTINUE
      IDA=31
      PRINT 923,IDA,SFW24(IPT,10,31),SFW24(IPT,12,31),
     1SFW24(IPT,1,31),SFW24(IPT,3,31),SFW24(IPT,5,31),
     2SFW24(IPT,7,31),SFW24(IPT,8,31)
      CONV=.011574*AREA(IPT)
      WYFLOW=0.0
      DO 144 MO=1,12
      TEMPOR=SSF(IPT,MO)
      SCM(MO)=TEMPOR/CONV
144   WYFLOW=WYFLOW+TEMPOR
      PRINT 924,(SSF(IPT,MO),MO=10,12),(SSF(IPT,MO),MO=1,9),WYFLOW
      WYSCM=WYFLOW/CONV
      PRINT 925,(SCM(MO),MO=10,12),(SCM(MO),MO=1,9),WYSCM
      IF (COMPAR(IPT).EQ.0) GO TO 141
      WYFLOW=-0.001
      DO 145 MO=1,12
      TEMPOR=SOF(IPT,MO)
      IF (TEMPOR.LT.0.0) GO TO 146
      OCM(MO)=TEMPOR/CONV
      WYFLOW=WYFLOW+TEMPOR
      GO TO 145
146   SOF(IPT,MO)=-0.01
```

```
      OCM(MO)=-0.0001
  145 CONTINUE
      PRINT 927,(SOF(IPT,MO),MO=10,12),(SOF(IPT,MO),MO=1,9),WYFLOW
      WYOCM=WYFLOW/CONV
      PRINT 925,(OCM(MO),MO=10,12),(OCM(MO),MO=1,9),WYOCM
      DO 120 MO=1,12
      IF (OCM(MO).LT.0.0) GO TO 121
      DCM(MO)=SCM(MO)-OCM(MO)
      GO TO 120
  121 DCM(MO)=-0.0001
  120 CONTINUE
      WYFLOW=WYSCM-WYOCM
      PRINT 926,(DCM(MO),MO=10,12),(DCM(MO),MO=1,9),WYFLOW
  141 CONTINUE
C PLOTTING OF SIMULATED VERSUS OBSERVED MEAN DAILY FLOW -- BY WATER YEAR
  149 IF (PTEST.EQ.0) GO TO 160
      LPI=0
      DO 151 IPT=1,NPTS
      IF (PLOT(IPT).EQ.0) GO TO 151
      IF (LPI.EQ.1) GO TO 153
      IF (MDFTBL.EQ.1) GO TO 156
      PRINT 928
      IF (LINEP.GT.0) CALL LPLOT
      IF (LINEP.EQ.1) GO TO 150
      IF (LINEP.EQ.0) GO TO 157
      DO 158 I=1,4
  158 PRINT 921
  157 CALL DAILY
  150 LPI=1
      GO TO 151
  156 LN=3
      IF (COMPAR(NPTS).EQ.0)LN=LN+5
      DO 154 I=1,LN
  154 PRINT 921
      LPI=1
  153 DO 155 I=1,4
  155 PRINT 921
      IF (LINEP.GT.0) CALL LPLOT
      IF (LINEP.EQ.1) GO TO 151
      IF (LINEP.EQ.0) GO TO 152
      DO 159 I=1,4
  159 PRINT 921
  152 CALL DAILY
  151 CONTINUE
  160 IF (STAT.EQ.0) GO TO 170
      DO 175 IPT=1,NPTS
      IF (COMPAR(IPT).EQ.0) GO TO 175
      CALL STASUM(STAT,YR2,IPT,FSFLOW,USGSID,YR1,MONTH,YEAR,IYEAR1)
  175 CONTINUE
  170 CONTINUE
C SUMARY FORMAT STATEMENTS
  900 FORMAT (1H1,40X,24HAREAL WATER YEAR SUMMARY,5X,13HUNITS ARE MM.)
  901 FORMAT (1H0,30X,11HAREA NUMBER,I3,5X,5A4,5X,13HWATER YEAR 19,I2)
  903 FORMAT (1H0,50X,32HSOIL MOISTURE ACCOUNTING VOLUMES)
  904 FORMAT (1H ,10X,5HMONTH,2X,8HTOTAL-RO,3X,7HIMPV-RO,1X,9HDIRECT-RO,
     13X,7HSURF-RO,1X,9HINTERFLOW,3X,7HCHANNEL,1X,11HNON-CHANNEL,2X,
     29HRAIN+MELT,2X,12HPOTENTIAL-ET,2X,9HACTUAL-ET)
```

```
  905 FORMAT (1H ,10X,A4,1X,7F10.1,F13.1,2F10.1)
  906 FORMAT (1H0,10X,5HTOTAL,7F10.1,F13.1,2F10.1)
 907  FORMAT (1H0,26X,39HSOIL MOISTURE VARIABLES AT END OF MONTH)
 908  FORMAT (1H+,100X,12HSNOW SUMMARY)
  909 FORMAT (1H0, 7X,5HMONTH,5X,5HUZTWC,3X,5HUZFWC,3X,5HLZTWC,3X,
     15HLZFSC,3X,5HLZFPC,2X,6HLZDEFR,3X,5HADIMC,3X,7HBALANCE)
 910  FORMAT (1H+,80X,2X,8HSNOWFALL,6X,4HRAIN,2X,9HRAIN+MELT,2X,
     17HBALANCE)
  911 FORMAT (1H , 8X,A4,2X,5F8.0,F8.2,F8.0,F10.2)
 912  FORMAT (1H+,80X,3F10.1,F10.2)
 913  FORMAT (1H0, 7X,5HTOTAL,68X,3F10.1)
  914 FORMAT (1H0,72X,8HBASEFLOW)
915   FORMAT (1H1,25X,24HWATER YEAR SUMMARY FOR--,5A4)
916   FORMAT (1H0,37X,13HWATER YEAR 19,I2)
  917 FORMAT (1H0,38HMEAN DAILY SIMULATED DISCHARGE SUMMARY,5X,
     131HUNITS ARE CUBIC METERS/SEC DAYS)
918   FORMAT (1H0,3X,3HDAY,5X,3HOCT,6X,3HNOV,6X,3HDEC,6X,3HJAN,6X,3HFEB,
     14X,5HMARCH,4X,5HAPRIL,6X,3HMAY,5X,4HJUNE,5X,4HJULY,3X,6HAUGUST,5X,
     24HSEPT,7X,6HANNUAL)
919   FORMAT (1H0)
  920 FORMAT (1H ,I5,12F9.3)
921   FORMAT (1H )
  922 FORMAT (1H ,I5,4F9.3,9X,7F9.3)
  923 FORMAT (1H ,I5,F9.3,9X,2F9.3,9X,F9.3,9X,F9.3,9X,2F9.3)
  924 FORMAT (1H0,5HTOTAL,12F9.2,F10.1,5H CMSD)
  925 FORMAT (1H ,5X,12F9.1,F10.0,5H   MM)
  926 FORMAT (1H0,5HDIFF.,12F9.1,F10.0,5H   MM)
  927 FORMAT (1H0,5HOBSV.,12F9.2,F10.1,5H CMSD)
928   FORMAT (1H1)
  929 FORMAT (1H0,15X,56HLZDEFR IS THE LOWER ZONE SOIL MOISTURE DEFICIEN
     1CY RATIO.)
      RETURN
      END
```

●PRT,S .STASUM

MORRIS*TPF$(0).STASUM

```
      SUBROUTINE STASUM(IOPT,YR2,IPT,SPEC,USGSID,YR1,MONTH,YEAR,IYEAR1)
C SUBROUTINE STASUM IS A STATISTICAL SUBROUTINE FOR GIVEN MEAN DAILY FLOW DATA.
C THE DATA MUST BE OVER A CONTINUOUS PERIOD, BUT MAY BEGIN OR END ON ANY DATE
C OF A WATER YEAR. THE FOLLOWING OPTIONS ARE AVAILABLE.....
C     IOPT=1  PRINT ONLY MULTIYEAR SUMMARY, PUNCH MEAN DAILIES IN STANDARD FORMAT
C     IOPT=2  PRINT ONLY MULTIYEAR SUMMARY
C     IOPT=3  PRINT YEAR SUMMARY AND MULTIYEAR SUMMARY
C     IOPT=4  PRINT YEAR SUMMARY AND MULTIYEAR SUMMARY, PUNCH M.D. IN STD FORMAT
C THE FOLLOWING MUST BE DEFINED IN CALLING PROGRAM BEFORE ENTERING THIS
C SUBROUTINE....
C     IOPT (SEE ABOVE)
C     YR1=1ST YEAR OF GIVEN DATA
C     YR2=LAST YEAR OF GIVEN DATA
C     YEAR=YEAR OF DATA BEING CALLED
C     IPT=FLOWPOINT NUMBER
C     SPEC(IPT)=ABOVE BANK OR OTHER FLOW VALUE ABOVE WHICH STATISTICAL VALUES
C               WILL BE COMPUTED
C     USGSID(IPT)=U.S. GEOLOGICAL SURVEY STREAM GAGE IDENTIFICATION NUMBER
C     FPNAME(IPT,7)=NAME OF FLOWPOINT
C     WYFW24(IPT,MO,IDA)=OBSERVED MEAN DAILIES FOR YEAR
C     SFW24(IPT,MO,IDA)=SIMULATED MEAN DAILIES FOR YEAR
C THIS SUBROUTINE COMPUTES STATISTICAL VALUES FOR EACH MONTH,TOTAL YEAR,EACH
C FLOW INTERVAL (FLOW INTERVALS ARE COMPUTED FROM SPEC(IPT)),ABOVE SPEC(IPT),
C AND A MULTIYEAR SUMMARY WHICH INCLUDES ALL THE ABOVE. COLUMN HEADINGS ON
C OUTPUT ARE SUFFICIENT EXPLANATION OF STATISTICAL VALUES FOUND.
      INTEGER YEAR,YR1,YR2,T1,T2,USGSID(3)
      DIMENSION A(36),ID(12),IQ(12),XVAL(9),YVAL(9),XLL(10),SPEC(3),
     1LL(10),XLU(10),LU(10),SO2(3),TN(3),OM1(3),SM1(3),SK1(3,12,9),
     2SK2(3,10,7),ISIM(31),NB(5),LB(52),IYEAR1(3),NC(3)
C DAILY PLOT DATA ARRAYS
      COMMON/PD/DPX(3,12,31),SFW24(3,12,31),WYFW24(3,12,31)
C TIME SERIES IDENTIFICATIONS AND DESCRIPTIONS.
      COMMON/TSID/AID(5,3),ANAME(5,5),PEID(3,3),FPNAME(6,5)
      EQUIVALENCE (XVAL(1),XO),(XVAL(2),XS),(XVAL(3),XOS),(XVAL(4),XO2),
     1(XVAL(5),XS2),(XVAL(6),XN),(XVAL(7),XMAX),(XVAL(8),XOM1),(XVAL(9),
     2XSM1),(YVAL(1),YO),(YVAL(2),YS),(YVAL(3),YOS),(YVAL(4),YO2),(YVAL(
     35),YS2),(YVAL(6),YN),(YVAL(7),YMAX),(YVAL(8),YOM1),(YVAL(9),YSM1)
      DATA IQ/31,28,31,30,31,30,31,31,30,31,30,31/
      DATA ID/10,11,12,1,2,3,4,5,6,7,8,9/
      DATA A/3HJAN,3HUAR,3HY  ,3HFEB,3HRUA,3HRY ,3HMAR,3HCH ,3H   ,3HAPR
     1,3HIL ,3H   ,3HMAY,3H   ,3H   ,3HJUN,3HE  ,3H   ,3HJUL,3HY  ,3H
     2,3HAUG,3HUST,3H   ,3HSEP,3HTEM,3HBER,3HOCT,3HOBE,3HR  ,3HNOV,3HEMB
     3,3HER ,3HDEC,3HEMB,3HER /
      DATA NB/25,16,12,9,7/
COMMENT...TEST FOR FIRST YEAR
      IF ((IYEAR1(IPT).NE.YR1).AND.(IYEAR1(IPT).NE.(YR1+1))) GO TO 4
      GO TO 1
COMMENT...ZERO PRELIMINARIES-MULTIYEAR MONTH AND INTERVAL
    4 IYEAR1(IPT)=YEAR
      IF (MONTH.GT.9) IYEAR1(IPT)=YEAR+1
      NC(IPT)=1
      TN(IPT)=0.
      OM1(IPT)=0.
      SM1(IPT)=0.
      SO2(IPT)=0.
      DO 2 I=1,12
```

```
          DO 2 J=1,9
        2 SK1(IPT,I,J)=0.
          DO 3 I=1,10
          DO 3 J=1,7
        3 SK2(IPT,I,J)=0.
COMMENT...TEST FOR LEAP YEAR
        1 IF(YEAR-4*(YEAR/4)) 12,11,12
       11 IQ(2)=29
          GO TO 13
       12 IQ(2)=28

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                              C
C*********START OF MONTH AND YEAR SECTION OF SUBROUTINE STASUM*****************C
C                                                                              C
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COMMENT...TEST FOR PRINT OPTION
       13 IF(IOPT.LT.3) GO TO 60
          IDYR2=1900+YEAR
          IF (MONTH.GT.9) IDYR2=IDYR2+1
          PRINT 1000,(FPNAME(IPT,I),I=1,5),IDYR2
          PRINT 1100
COMMENT...ZERO PRELIMINARIES-YEAR
        5 DO 10 II=1,9
       10 YVAL(II)=0.
          YSO2=0.
          MYR=1
COMMENT...START OF MONTH LOOP**********************************************
          DO 100 I=1,12                                                   *
          MO=ID(I)                                                        *
          N=IQ(MO)                                                        *
          T2=3*MO                                                         *
          T1=T2-2                                                         *
COMMENT...ZERO PRELIMINARIES-MONTH                                        *
          DO 20 II=1,9                                                    *
       20 XVAL(II)=0.                                                     *
COMMENT...TEST FOR MISSING DATA                                           *
          TEMP=0.                                                         *
          NM=0
          DO 25 IDA=1,N                                                   *
          IF (WYFW24(IPT,MO,IDA).LT.0.0) NM=NM+1
       25 TEMP=WYFW24(IPT,MO,IDA)+TEMP
C  MONTH NOT INCLUDED IF MORE THAN 25 MISSING DAYS
          IF (NM.LT.26) GO TO 26
       28 PRINT 1103,(A(J),J=T1,T2)
          IF (TEMP.GT.-0.001) GO TO 100
          GO TO 41
COMMENT...START OF DAY LOOP************************************************
26        MYR=0
          DO 30 IDA=1,N
COMMENT...PRELIMINARIES-MONTH                                            **
          OBS=WYFW24(IPT,MO,IDA)                                         **
          IF (OBS.LT.0.0) GO TO 30
          SIM=SFW24(IPT,MO,IDA)                                          **
          T=SIM-OBS                                                      **
          XO=XO+OBS                                                      **
```

```
      XS=XS+SIM
      XOS=XOS+SIM*OBS
      XS2=XS2+SIM*SIM
      XO2=XO2+OBS*OBS
      XN=XN+1.
      IF(ABS(T).GT.ABS(XMAX))XMAX=T
      XSM1=XSM1+XN*SIM
      XOM1=XOM1+XN*OBS
COMMENT...PRELIMINARIES-YEAR
      YN=YN+1.
      YSM1=YSM1+YN*SIM
      YOM1=YOM1+YN*OBS
      YSO2=YSO2+T*T
COMMENT...PRELIMINARIES-MULTIYEAR END
      TN(IPT)=TN(IPT)+1.
      OM1(IPT)=OM1(IPT)+TN(IPT)*OBS
   30 SM1(IPT)=SM1(IPT)+TN(IPT)*SIM
COMMENT...END OF DAY LOOP**************************************************
COMMENT...PRELIMINARIES-YEAR AND MULTIYEAR MONTH
      DO 35 J=1,5
      YVAL(J)=YVAL(J)+XVAL(J)
   35 SK1(IPT,MO,J)=SK1(IPT,MO,J)+XVAL(J)
      IF(ABS(XMAX).GT.ABS(YMAX)) YMAX=XMAX
      SK1(IPT,MO,6)=SK1(IPT,MO,6)+XN
      IF(ABS(XMAX).GT.ABS(SK1(IPT,MO,7))) SK1(IPT,MO,7)=XMAX
      SK1(IPT,MO,8)=SK1(IPT,MO,8)+XOM1
      SK1(IPT,MO,9)=SK1(IPT,MO,9)+XSM1
COMMENT...CALCULATIONS -MONTH
      XOBSM=XO/XN
      XSIMM=XS/XN
      XBIAS=XSIMM-XOBSM
      IF(XOBSM) 38,39,38
   38 IF(XSIMM) 36,39,36
   39 XA0=0.
      XPBIAS=0.
      XMIVAL=0.
      XA1=0.
      XSTER=0.
      XPSTER=0.
      XR=0.
      GO TO 37
   36 XA0=(XO*XS2-XS*XOS)/(XN*XS2-XS*XS)
      XPBIAS=(100.*XBIAS)/XOBSM
      XMIVAL=XSM1/XS-XOM1/XO
      XA1=(XN*XOS-XS*XO )/(XN*XS2-XS*XS)
      IF(ABS(XA1).LT.0.01) GO TO 40
      XSTER=SQRT((XO2-XA0*XO-XA1*XOS)/XN)
      XPSTER=(100.*XSTER)/XOBSM
      XR=(XN*XOS-XO*XS)/SQRT((XN*XS2-XS*XS)*(XN*XO2-XO*XO))
      GO TO 37
   40 XSTER=0.0
      XPSTER=0.0
      XR=1.0
   37 PRINT 1101,(A(J),J=T1,T2),XSIMM,XOBSM,XBIAS,XPBIAS,XMIVAL,XMAX,
     1XSTER,XPSTER,XR,XA0,XA1
COMMENT...TEST FOR STANDARD FORMAT PUNCH OPTION
   41 IF(IOPT.LT.4) GO TO 100
```

```
COMMENT...STANDARD FORMAT PUNCHES
   50 LYR=YEAR-1
      IF(MO.LT.10) LYR=YEAR
      IF (MONTH.GT.9) LYR=YEAR
      DO 51 K=1,N
   51 ISIM(K)=SFW24(IPT,MO,K)*100.0+0.5
      IDAY=1
   52 MX=10
      DO 54 J=1,5
      MX=MX*10
      LDAY=IDAY+NB(J)
      IF(LDAY.GT.N) LDAY=N
      DO 53 K=IDAY,LDAY
      IF(ISIM(K)-MX) 53,54,54
   53 CONTINUE
      GO TO 55
   54 CONTINUE
   55 LF=J+1
      DO 56 K=1,52
   56 LB(K)=0
      DO 58 L=IDAY,LDAY
      DO 57 M=1,LF
      MM=LF+1-M
      NN=M+LF*(L-IDAY)
      LB(NN)=ISIM(L)/10**(MM-1)
   57 ISIM(L)=ISIM(L)-LB(NN)*10**(MM-1)
   58 CONTINUE
      II=LF*(LDAY-IDAY+1)
      PUNCH 1600,NC(IPT),LF,USGSID(IPT),IDAY,MO,LYR,(LB(K),K=1,II)
      NC(IPT)=NC(IPT)+1
      IDAY=LDAY+1
      IF(LDAY-N) 52,100,100
  100 CONTINUE
COMMENT...END OF MONTH LOOP************************************************
      IF (MYR.EQ.0) GO TO 90
C     ENTIRE YEAR OF MISSING DATA
      PRINT 1104
      GO TO 360
90    SO2(IPT)=SO2(IPT)+YSO2
COMMENT...CALCULATIONS-YEAR
      YOBSM=YO/YN
      YSIMM=YS/YN
      YBIAS=YSIMM-YOBSM
      IF(YOBSM) 91,92,91
   91 IF(YSIMM) 93,92,93
   92 YPBIAS=0.
      YMIVAL=0.
      YA0=0.
      YA1=0.
      YSTER=0.
      YPSTER=0.
      YR=0.
      GO TO 94
   93 YPBIAS=(100.*YBIAS)/YOBSM
      YMIVAL=YSMI/YS-YOMI/YO
      YA0=(YO*YS2-YS*YOS)/(YN*YS2-YS*YS)
      YA1=(YN*YOS-YS*YO )/(YN*YS2-YS*YS)
```

```
      IF(ABS(YA1).LT.0.01) GO TO 95
      YSTER=SQRT((YO2-YA0*YO-YA1*YOS)/YN)
      YPSTER=(100.*YSTER)/YOBSM
      YR=(YN*YOS-YO*YS)/SQRT((YN*YS2-YS*YS)*(YN*YO2-YO*YO))
      GO TO 94
   95 YSTER=0.0
      YPSTER=0.0
      YR=1.0
   94 PRINT 1102,YSIMM,YOBSM,YBIAS,YPBIAS,YMIVAL,YMAX,YSTER,YPSTER,YR,
     1YA0,YA1
      RM=SQRT(YSO2/YN)
      PRINT 1300,YSO2,RM
      GO TO 101

COMMENT...NON PRINT PART OF MONTH AND YEAR SECTION OF STASUM***************
   60 DO 80 I=1,12                                                      ***
      MO=ID(I)                                                          ***
      N=IQ(MO)                                                          ***
      TEMP=0.                                                           ***
      NM=0
      DO 61 IDA=1,N                                                     ***
      IF (WYFW24(IPT,MO,IDA).LT.0.0) NM=NM+1
   61 TEMP=WYFW24(IPT,MO,IDA)+TEMP
C  MONTH NOT INCLUDED IF MORE THAN 25 MISSING DAYS
      IF (NM.LT.26) GO TO 62
      IF (TEMP.GT.-0.001) GO TO 80
      GO TO 63
   62 DO 70 IDA=1,N                                                     ***
      OBS=WYFW24(IPT,MO,IDA)                                            ***
      IF (OBS.LT.0.0) GO TO 70
      SIM=SFW24(IPT,MO,IDA)                                             ***
      T=SIM-OBS                                                         ***
      FIDA=IDA
      SK1(IPT,MO,1)=SK1(IPT,MO,1)+OBS                                   ***
      SK1(IPT,MO,2)=SK1(IPT,MO,2)+SIM                                   ***
      SK1(IPT,MO,3)=SK1(IPT,MO,3)+SIM*OBS                               ***
      SK1(IPT,MO,4)=SK1(IPT,MO,4)+OBS*OBS                               ***
      SK1(IPT,MO,5)=SK1(IPT,MO,5)+SIM*SIM                               ***
      SK1(IPT,MO,6)=SK1(IPT,MO,6)+1.                                    ***
      IF(ABS(T).GT.ABS(SK1(IPT,MO,7))) SK1(IPT,MO,7)=T                  ***
      SK1(IPT,MO,8)=SK1(IPT,MO,8)+FIDA*OBS
      SK1(IPT,MO,9)=SK1(IPT,MO,9)+FIDA*SIM
      TN(IPT)=TN(IPT)+1.                                                ***
      OM1(IPT)=OM1(IPT)+TN(IPT)*OBS                                     ***
      SM1(IPT)=SM1(IPT)+TN(IPT)*SIM                                     ***
      SO2(IPT)=SO2(IPT)+T*T                                             ***
   70 CONTINUE                                                          ***
COMMENT...TEST FOR STANDARD FORMAT PUNCH OPTION                         ***
   63 IF(IOPT.GT.1) GO TO 80
COMMENT...STANDARD FORMAT PUNCHES                                       ***
   71 LYR=YEAR-1
      IF(MO.LT.10) LYR=YEAR
      IF (MONTH.GT.9) LYR=YEAR
      DO 72 K=1,N                                                       ***
   72 ISIM(K)=SFW24(IPT,MO,K)*100.0+0.5
      IDAY=1                                                            ***
   73 MX=10                                                             ***
```

```
      DO 75 J=1,5                                                       ***
      MX=MX*10                                                          ***
      LDAY=IDAY+NB(J)                                                   ***
      IF(LDAY.GT.N) LDAY=N                                              ***
      DO 74 K=IDAY,LDAY                                                 ***
      IF(ISIM(K)-MX) 74,75,75                                           ***
   74 CONTINUE                                                          ***
      GO TO 76                                                          ***
   75 CONTINUE                                                          ***
   76 LF=J+1                                                            ***
      DO 77 K=1,52                                                      ***
   77 LB(K)=0                                                           ***
      DO 79 L=IDAY,LDAY                                                 ***
      DO 78 M=1,LF                                                      ***
      MM=LF+1-M                                                         ***
      NN=M+LF*(L-IDAY)                                                  ***
      LB(NN)=ISIM(L)/10**(MM-1)                                         ***
   78 ISIM(L)=ISIM(L)-LB(NN)*10**(MM-1)                                 ***
   79 CONTINUE                                                          ***
      II=LF*(LDAY-IDAY+1)                                               ***
      PUNCH 1600,NC(IPT),LF,USGSID(IPT),IDAY,MO,LYR,(LB(K),K=1,II)
      NC(IPT)=NC(IPT)+1
      IDAY=LDAY+1                                                       ***
      IF(LDAY-N) 73,80,80                                               ***
   80 CONTINUE                                                          ***
C***********************************************************************

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                              C
C***********END OF MONTH AND YEAR SECTION OF SUBROUTINE STASUM*****************C
C                                                                              C
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C                                                                              C
C*********START OF INTERVAL AND ABOVE SPEC SECTION OF SUBROUTINE STASUM********C
C                                                                              C
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COMMENT...INTERVAL DETERMINATION
  101 DO 110 J=2,9
      S=J
      K=J+1
      TEMP=K
      XLL(K)=(TEMP/6.)**4.5*(SPEC(IPT)-1.)+1.
      XLL(J)=(   S/6.)**4.5*(SPEC(IPT)-1.)+1.
      LL(J)=XLL(J)
      XLU(J)=XLL(K)-.001
  110 LU(J)=XLL(K)
      XLL(1)=0.
      LL(1)=0
      XLU(1)=XLL(2)-.001
      LU(1)=XLL(2)
      LL(10)=XLL(10)
      XLU(10)=10.**10
      ISPEC=SPEC(IPT)
COMMENT...TEST FOR PRINT OPTION
```

```
      IF(IOPT.LT.3) GO TO 300
      PRINT 1200
COMMENT...ZERO PRELIMINARIES-ABOVE SPEC
      DO 130 J=1,7
  130 YVAL(J)=0.
COMMENT...START OF INTERVAL LOOP
      DO 200 INT=1,10
COMMENT...ZERO PRELIMINARIES-INTERVAL
      DO 210 J=1,7
  210 XVAL(J)=0.
COMMENT...START OF MONTH LOOP
      DO 230 I=1,12
      MO=ID(I)
      N=IQ(MO)
COMMENT...START OF DAY LOOP
      DO 230 IDA=1,N
COMMENT...PRELIMINARIES-INTERVAL
      OBS=WYFW24(IPT,MO,IDA)
COMMENT...TEST TO PLACE IN INTERVAL
      IF(OBS-XLL(INT)) 230,215,215
  215 IF(OBS-XLU(INT)) 216,216,230
  216 SIM=SFW24(IPT,MO,IDA)
      T=SIM-OBS
      XO=XO+OBS
      XS=XS+SIM
      XOS=XOS+SIM*OBS
      XS2=XS2+SIM*SIM
      XO2=XO2+OBS*OBS
      XN=XN+1.
      IF(ABS(T).GT.ABS(XMAX)) XMAX=T
  230 CONTINUE
COMMENT...END OF DAY LOOP
COMMENT...END OF MONTH LOOP
COMMENT...TEST FOR MISSING DATA
      IF(XN) 240,250,240
  250 IF(INT-10) 252,251,252
  251 PRINT 1204,LL(10)
      GO TO 200
  252 PRINT 1203,LL(INT),LU(INT)
      GO TO 200
COMMENT...PRELIMINARIES-MULTIYEAR INTERVAL
  240 DO 255 J=1,6
  255 SK2(IPT,INT,J)=SK2(IPT,INT,J)+XVAL(J)
      IF(ABS(XMAX).GT.ABS(SK2(IPT,INT,7)))  SK2(IPT,INT,7)=XMAX
COMMENT...TEST FOR INTERVAL ABOVE SPEC
      IF(INT-6)  235,242,242
COMMENT...PRELIMINARIES-ABOVE SPEC
  242 DO 241 J=1,6
  241 YVAL(J)=YVAL(J)+XVAL(J)
      IF(ABS(XMAX).GT.ABS(YMAX)) YMAX=XMAX
COMMENT...CALCULATIONS-INTERVAL
  235 XOBSM=XO/XN
      XSIMM=XS/XN
      XBIAS=XSIMM-XOBSM
      IN=XN
      IF(XSIMM) 245,239,245
  245 IF(XOBSM) 238,239,238
```

```
      COMMENT...TEST FOR ONLY ONE POINT IN DATA SET
        238 IF(IN.NE.1) GO TO 236
            XPBIAS=0.
        239 XA0=0.
            XA1=0.
            XSTER=0.
            XPSTER=0.
            XR=0.
            GO TO 237
        236 XA0=(XO*XS2-XS*XOS)/(XN*XS2-XS*XS)
            XPBIAS=(100.*XBIAS)/XOBSM
            XA1=(XN*XOS-XS*XO )/(XN*XS2-XS*XS)
            IF(ABS(XA1).LT.0.01) GO TO 259
            IF(XN.GT.2.1) GO TO 233
            XSTER=0.
            GO TO 234
        233 XSTER=SQRT((ABS(XO2-XA0*XO-XA1*XOS))/XN)
        234 XPSTER=(100.*XSTER)/XOBSM
            XR=(XN*XOS-XO*XS)/SQRT((XN*XS2-XS*XS)*(XN*XO2-XO*XO))
            GO TO 237
        259 XSTER=0.0
            XPSTER=0.0
            XR=1.0
      COMMENT...TEST FOR LAST INTERVAL
        237 IF(INT.NE.10) GO TO 260
            PRINT 1202,LL(10),IN,XOBSM,XSIMM,XBIAS,XPBIAS,XMAX,XSTER,XPSTER,
           1XR,XA0,XA1
            GO TO 200
        260 PRINT 1201,LL(INT),LU(INT),IN,XOBSM,XSIMM,XBIAS,XPBIAS,XMAX,XSTER,
           1XPSTER,XR,XA0,XA1
        200 CONTINUE
      COMMENT...END OF INTERVAL LOOP•••••••••••••••••••••••••••••••••••••••••••••••
      COMMENT...TEST FOR MISSING DATA
            IF(YN.NE.0.) GO TO 270
            PRINT 1204,ISPEC
            GO TO 360
      COMMENT...CALCULATIONS-ABOVE SPEC
        270 YOBSM=YO/YN
            YSIMM=YS/YN
            YBIAS=YSIMM-YOBSM
            JN=YN
            IF(YSIMM) 271,273,271
        271 IF(YOBSM) 272,273,272
      COMMENT...TEST FOR ONLY ONE POINT IN DATA SET
        272 IF(JN.NE.1) GO TO 280
        273 YA0=0.
            YPBIAS=0.
            YA1=0.
            YSTER=0.
            YPSTER=0.
            YR=0.
            GO TO 290
        280 YA0=(YO*YS2-YS*YOS)/(YN*YS2-YS*YS)
            YPBIAS=(100.*YBIAS)/YOBSM
            YA1=(YN*YOS-YS*YO )/(YN*YS2-YS*YS)
            IF(ABS(YA1).LT.0.01) GO TO 289
            IF(YN.GT.2.1) GO TO 281
```

```
      YSTER=0.
      GO TO 282
  281 YSTER=SQRT((YO2-YA0*YO-YA1*YOS)/YN)
  282 YPSTER=(100.*YSTER)/YOBSM
      YR=(YN*YOS-YO*YS)/SQRT((YN*YS2-YS*YS)*(YN*YO2-YO*YO))
      GO TO 290
  289 YSTER=0.0
      YR=1.0
      YPSTER=0.0
  290 PRINT 1202,ISPEC,JN,YOBSM,YSIMM,YBIAS,YPBIAS,YMAX,YSTER,YPSTER,YR,
     1YA0,YA1
      GO TO 360

COMMENT...NON PRINT PART OF INTERVAL AND ABOVE SPEC SECTION OF STASUM*******
  300 DO 350 INT=1,10                                                    ***
      DO 310 J=1,7                                                       ***
  310 XVAL(J)=0.                                                         ***
      DO 320 I=1,12                                                      ***
      MO=ID(I)                                                           ***
      N=IQ(MO)                                                           ***
      DO 320 IDA=1,N                                                     ***
      OBS=WYFW24(IPT,MO,IDA)                                             ***
      IF(OBS-XLL(INT)) 320,315,315                                       ***
  315 IF(OBS-XLU(INT)) 316,316,320                                       ***
  316 SIM=SFW24(IPT,MO,IDA)                                              ***
      T=SIM-OBS                                                          ***
      XO=XO+OBS                                                          ***
      XS=XS+SIM                                                          ***
      XOS=XOS+OBS*SIM                                                    ***
      XS2=XS2+SIM*SIM                                                    ***
      XO2=XO2+OBS*OBS                                                    ***
      XN=XN+1.                                                           ***
      IF(ABS(T).GT.ABS(XMAX)) XMAX=T                                     ***
  320 CONTINUE                                                           ***
      IF(XN) 335,350,335                                                 ***
  335 DO 340 J=1,6                                                       ***
  340 SK2(IPT,INT,J)=SK2(IPT,INT,J)+XVAL(J)                              ***
      IF(ABS(XMAX).GT.ABS(SK2(IPT,INT,7)))  SK2(IPT,INT,7)=XMAX          ***
  350 CONTINUE                                                           ***
C***************************************************************************

COMMENT...TEST TO ENTER MULTIYEAR SECTION
  360 IF(YEAR-YR2) 370,400,370
  370 CONTINUE
      RETURN

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C                                                                          C
C***********END OF INTERVAL AND ABOVE SPEC SECTION OF SUBROUTINE STASUM********C
C                                                                          C
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CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                          C
C*********START OF MULTIYEAR SECTION OF SUBROUTINE STASUM*********************C
C                                                                          C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
```

```
  400 IDYR1=1900+IYEAR1(IPT)
      IDYR2=1900+YR2
      IF (MONTH.GT.9) IDYR2=IDYR2+1
      PRINT 1500,(FPNAME(IPT,I),I=1,5),IDYR1,IDYR2
      PRINT 1100
COMMENT...ZERO PRELIMINARIES-MULTIYEAR END
      DO 410 J=1,7
  410 YVAL(J)=0.
      IQ(2)=29
COMMENT...START OF MONTH LOOP**********************************************
      DO 415 I=1,12
      MO=ID(I)
      T2=3*MO
      T1=T2-2
COMMENT...PRELIMINARIES-MULTIYEAR MONTH
      DO 412 J=1,9
  412 XVAL(J)=SK1(IPT,MO,J)
COMMENT...CALCULATIONS-MULTIYEAR MONTH
      IF (XN.EQ.0.0) GO TO 414
      XSIMM=XS/XN
      XOBSM=XO/XN
      XBIAS=XSIMM-XOBSM
      IF(XSIMM) 414,417,416
  416 IF(XOBSM) 414,417,418
  417 XPBIAS=0.
      XMIVAL=0.
      XA0=0.
      XA1=0.
      XSTER=0.
      XPSTER=0.
      XR=0.
      GO TO 419
  414 PRINT 1103,(A(J),J=T1,T2)
      GO TO 413
  418 XPBIAS=(100.*XBIAS)/XOBSM
      XMIVAL=XSMI/XS - XOMI/XO
      XA0=(XO*XS2-XS*XOS)/(XN*XS2-XS*XS)
      XA1=(XN*XOS-XS*XO )/(XN*XS2-XS*XS)
      IF(ABS(XA1).LT.0.01) GO TO 411
      XSTER=SQRT((XO2-XA0*XO-XA1*XOS)/XN)
      XPSTER=(100.*XSTER)/XOBSM
      XR=(XN*XOS-XO*XS)/SQRT((XN*XS2-XS*XS)*(XN*XO2-XO*XO))
      GO TO 419
  411 XSTER=0.0
      XPSTER=0.0
      XR=1.0
  419 PRINT 1101,(A(J),J=T1,T2),XSIMM,XOBSM,XBIAS,XPBIAS,XMIVAL,XMAX,
     1XSTER,XPSTER,XR,XA0,XA1
COMMENT...PRELIMINARIES-MULTIYEAR END
  413 DO 420 J=1,6
  420 YVAL(J)=YVAL(J)+XVAL(J)
      IF(ABS(XMAX).GT.ABS(YMAX)) YMAX=XMAX
  415 CONTINUE
COMMENT...END OF MONTH LOOP************************************************
COMMENT...CALCULATIONS-MULTIYEAR END
      YOBSM=YO/YN
```

```
      YSIMM=YS/YN
      YBIAS=YSIMM-YOBSM
      IF(YOBSM) 421,422,421
  421 IF(YSIMM) 423,422,423
  422 YPBIAS=0.
      YMIVAL=0.
      YA0=0.
      YA1=0.
      YSTER=0.
      YPSTER=0.
      YR=0.
      GO TO 424
  423 YPBIAS=(100.*YBIAS)/YOBSM
      YMIVAL=SMI(IPT)/YS - OMI(IPT)/YO
      YA0=(YO*YS2-YS*YOS)/(YN*YS2-YS*YS)
      YA1=(YN*YOS-YS*YO )/(YN*YS2-YS*YS)
      IF(ABS(YA1).LT.0.01) GO TO 425
      YSTER=SQRT((YO2-YA0*YO-YA1*YOS)/YN)
      YPSTER=(100.*YSTER)/YOBSM
      YR=(YN*YOS-YO*YS)/SQRT((YN*YS2-YS*YS)*(YN*YO2-YO*YO))
      GO TO 424
  425 YSTER=0.0
      YPSTER=0.0
      YR=1.0
  424 PRINT 1102,YSIMM,YOBSM,YBIAS,YPBIAS,YMIVAL,YMAX,YSTER,YPSTER,YR,
     1YA0,YA1
      RM=SQRT(SO2(IPT)/YN)
      PRINT 1300,SO2(IPT),RM
      PRINT 1200
COMMENT...ZERO PRELIMINARIES-MULTIYEAR ABOVE SPEC
      DO 430 J=1,7
  430 YVAL(J)=0.
COMMENT...START OF INTERVAL LOOP*******************************************
      DO 440 INT=1,10                                                     *
COMMENT...PRELIMINARIES-MULTIYEAR INTERVAL                                *
      DO 470 J=1,7                                                        *
  470 XVAL(J)=SK2(IPT,INT,J)                                              *
COMMENT...TEST FOR MISSING DATA                                           *
      IF(XN) 472,471,472                                                  *
COMMENT...TEST FOR LAST INTERVAL                                          *
  471 IF(INT.NE.10) GO TO 474                                             *
      PRINT 1204,LL(10)                                                   *
      GO TO 440                                                           *
  474 PRINT 1203,LL(INT),LU(INT)                                          *
      GO TO 440                                                           *
COMMENT...CALCULATIONS-MULTIYEAR INTERVAL                                 *
  472 XOBSM=XO/XN                                                         *
      XSIMM=XS/XN                                                         *
      XBIAS=XSIMM-XOBSM                                                   *
      IN=XN                                                               *
      IF(XSIMM) 475,477,475
  475 IF(XOBSM) 476,477,476
COMMENT...TEST FOR ONLY ONE POINT IN DATA SET                             *
  476 IF(IN.NE.1) GO TO 465
  477 XA0=0.
      XPBIAS=0.
      XA1=0.                                                              *
```

```
            XSTER=0.                                                             *
            XPSTER=0.                                                            *
            XR=0.                                                                *
            GO TO 466                                                            *
        465 XA0=(XO*XS2-XS*XOS)/(XN*XS2-XS*XS)                                   *
            XPBIAS=(100.*XBIAS)/XOBSM                                            *
            XA1=(XN*XOS-XS*XO )/(XN*XS2-XS*XS)                                   *
            IF(ABS(XA1).LT.0.01) GO TO 464
            IF(XN.GT.2.1) GO TO 467
            XSTER=0.
            GO TO 468
        467 XSTER=SQRT((XO2-XA0*XO-XA1*XOS)/XN)                                  *
        468 XPSTER=(100.*XSTER)/XOBSM                                            *
            XR=(XN*XOS-XO*XS)/SQRT((XN*XS2-XS*XS)*(XN*XO2-XO*XO))                *
            GO TO 466
        464 XSTER=0.0
            XPSTER=0.0
            XR=1.0
      COMMENT...TEST FOR LAST INTERVAL                                           *
        466 IF(INT.NE.10) GO TO 450                                              *
            PRINT 1202,LL(10),IN,XOBSM,XSIMM,XBIAS,XPBIAS,XMAX,XSTER,XPSTER,     *
           1XR,XA0,XA1                                                           *
            GO TO 460                                                            *
        450 PRINT 1201,LL(INT),LU(INT),IN,XOBSM,XSIMM,XBIAS,XPBIAS,XMAX,XSTER,   *
           1XPSTER,XR,XA0,XA1                                                    *
      COMMENT...TEST FOR INTERVAL ABOVE SPEC                                     *
            IF(INT-6) 440,460,460                                                *
      COMMENT...PRELIMINARIES-MULTIYEAR ABOVE SPEC                               *
        460 DO 480 J=1,6                                                         *
        480 YVAL(J)=YVAL(J)+XVAL(J)                                              *
            IF(ABS(XMAX).GT.ABS(YMAX)) YMAX=XMAX                                 *
        440 CONTINUE                                                             *
      COMMENT...END OF INTERVAL LOOP**********************************************
      COMMENT...TEST FOR MISSING DATA
            IF(YN.NE.0.) GO TO 490
            PRINT 1204,ISPEC
            RETURN
      COMMENT...CALCULATIONS-MULTIYEAR ABOVE SPEC
        490 YOBSM=YO/YN
            YSIMM=YS/YN
            YBIAS=YSIMM-YOBSM
            JN=YN
            IF(YSIMM) 491,493,491
        491 IF(YOBSM) 492,493,492
      COMMENT...TEST FOR ONLY ONE POINT IN DATA SET
        492 IF(JN.NE.1) GO TO 495
        493 YA0=0.
            YPBIAS=0.
            YA1=0.
            YSTER=0.
            YPSTER=0.
            YR=0.
            GO TO 496
        495 YA0=(YO*YS2-YS*YOS)/(YN*YS2-YS*YS)
            YPBIAS=(100.*YBIAS)/YOBSM
            YA1=(YN*YOS-YS*YO )/(YN*YS2-YS*YS)
            IF(ABS(YA1).LT.0.01) C  TO 500
```

```
      IF(YN.GT.2.1) GO TO 498
      YSTER=0.
      GO TO 499
  498 YSTER=SQRT((YO2-YA0*YO-YA1*YOS)/YN)
  499 YPSTER=(100.*YSTER)/YOBSM
      YR=(YN*YOS-YO*YS)/SQRT((YN*YS2-YS*YS)*(YN*YO2-YO*YO))
      GO TO 496
  500 YSTER=0.0
      YPSTER=0.0
      YR=1.0
  496 PRINT 1202,ISPEC,JN,YOBSM,YSIMM,YBIAS,YPBIAS,YMAX,YSTER,YPSTER,YR,
     1YA0,YA1
      RETURN

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C***********END OF MULTIYEAR SECTION OF SUBROUTINE STASUM**************C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

COMMENT...START OF FORMATS
 1000 FORMAT(1H1,40X,20HSTATISTICAL SUMMARY ///1H ,20X,13HFLOW POINT = ,
     15A4,5X,12HWATER YEAR = ,I5//)
 1100 FORMAT(1H ,34X,4HBIAS,13X,10HIST MOMENT,22X,7HPERCENT,15X,13HBEST
     1FIT LINE/   12X,109HSIMULATED  OBSERVED (SIM MEAN  PERCENT  (SIM)-
     21ST    MAXIMUM  STANDARD  STANDARD    CORREL.   OBS = A + B *SIM /
     32X,5HMONTH,8X,4HMEAN,6X,4HMEAN,3X,31H-OBS MEAN)     BIAS  MOMENT(OB
     4S),3X,5HERROR,5X,5HERROR,5X,5HERROR,5X,5HCOEFF,6X,1HA,10X,1HB /1H
     5,120(1H.)/ )
 1101 FORMAT(1H ,3A3,1X,11F10.3)
 1102 FORMAT(1H ,120(1H.)/11H WATER YEAR,11F10.3/1H ,120(1H.)/////)
 1103 FORMAT(1H ,3A3,1X,14H  MISSING DATA )
1104  FORMAT(1H ,120(1H.)/11X,33HENTIRE YEAR MISSING OBSERVED DATA)
 1200 FORMAT(1H ,16X,6HNUMBER,61X,7HPERCENT,15X,13HBEST FIT LINE/7X, 36H
     1 FLOW    OF CASES OBSERVED SIMULATED,11X,67HPERCENT   MAXIMUM  STA
     2NDARD  STANDARD    CORREL.   OBS = A + B *SIM/5X,26H INTERVAL  OBS
     3ERVED   MEAN , 5X,4HMEAN,6X,4HBIAS,6X,4HBIAS,6X,3(5HERROR,5X),5HCO
     4EFF,6X,1HA,11X,1HB/1H ,120(1H.)/)
 1201 FORMAT(1H ,I6,2H -,I6,I6,10F10.3)
 1202 FORMAT(9H   ABOVE ,I6,I6,10F10.3/1H ,120(1H.))
 1203 FORMAT(1H ,I6,2H -,I6,' NO OBSERVED FLOW IN THIS INTERVAL')
 1204 FORMAT(9H   ABOVE ,I6,'  NO OBSERVED FLOW IN THIS INTERVAL'/1H ,
     1120(1H.))
 1300 FORMAT(31H **NOTE...SUM OF (SIM-OBS)**2 =,F20.0,39H.....ROOT MEAN
     1OF SUM OF (SIM-OBS)**2 =,F10.3,5H...**/////)
 1500 FORMAT(1H1,35X,30HMULTIYEAR STATISTICAL SUMMARY ///1H ,20X,12HFLOW
     1POINT = ,5A4,5X,12HWATER YEARS ,I4,4H TO ,I4//)
 1600 FORMAT (I4,I1,1H2,1X,I8,7H0240324,3I2,52I1)
COMMENT... END  OF FORMATS
      END

*PRT,S  .DAILY
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```
MORRIS*TPF$(0).DAILY
      SUBROUTINE DAILY
C     MEAN DAILY FLOW FOR PRINTER OUTPUT(SEMI-LOG PLOT)
      REAL MOCHAR(12)
      DIMENSION LASTDA(2,12),SCALE(2,5),ORD(101),LC(2,6)
C GENERAL PROGRAM VARIABLES
      INTEGER ROUTE,TRO,SNOW,SNOWA,YRIN,YR1,SGIN,TPTS,STORE,YEAR,PLT6HR,
     1SAVEFW,TSAVE,COMPAR,PTEST,PLOT,CTEST,      SIXIN,OBSER,STDA,STP6,
     2YR2,USGSID,STAT,PEG
      REAL  INFRO
      COMMON/G/MONTH,MOIN,LAST,ROUTE,NGAGES,TRO,SNOW,SNOWA(12),YRIN,
     1NPEGS,YR1,NPTS,SGIN(3),TPTS,STORE,BASIN(20),YEAR,SSF(3,12),
     2SOF(3,12),PLT6HR,SAVEFW,DUMMY(4,31),TSAVE,COMPAR(3),PTEST,PLOT(3),
     3LINEP,INFRO(20),PLOTMX(3),CTEST,FSFLOW(3),USGSID(3),PEG(5),STAT,
     4YR2,AREA(6),SIXIN(3),OBSER(3),STDA(2,10),STP6(2,10),IYEAR1(3),IPT,
     5METRIC(3)
C DAILY PLOT DATA ARRAYS
      COMMON/PD/DPX(3,12,31),SFW24(3,12,31),WYFW24(3,12,31)
C TIME SERIES IDENTIFICATIONS AND DESCRIPTIONS.
      COMMON/TSID/AID(5,3),ANAME(5,5),PEID(3,3),FPNAME(6,5)
      DATA MOCHAR/3HOCT,3HNOV,3HDEC,3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,3HJUN,
     13HJUL,3HAUG,3HSEP/
      DATA LASTDA/31,31,28,29,31,31,30,30,31,31,30,30,31,31,31,31,30,30,
     131,31,30,30,31,31/
      DATA LC/3,3,3,3,6,5,4,4,4,4,0,0/
      DATA DOT,BLANK,ASTER,PLUS/1H.,1H ,1H*,1H+/
      DATA SCALE/.001,.01,.01,.1,.1,1.0,1.0,10.,10.,100./
      QC=1.0
      ID=METRIC(IPT)+1
      IU=METRIC(IPT)
      IF (IU.GT.0) GO TO 801
      VERT=AREA(IPT)*26.88889*0.3861022
      QC=35.3147
      GO TO 802
  801 VERT=AREA(IPT)*.011574
  802 PMAX=ALOG(10.0)*5.0
      UNITY=4.0
      IF(IU.GT.0) UNITY=3.0
      CYL4=ALOG(10.0)*UNITY
      DO 816 I=1,100
      ORD(I)=BLANK
  816 CONTINUE
      DO 817 I=1,101,10
      ORD(I)=DOT
  817 CONTINUE
      LEAPYR=1
      IF ((YEAR-4*(YEAR/4)).EQ.0) LEAPYR=2
      DO 810 MONUM=1,12
      MO=MONUM+9
      IF (MO.GT.12) MO=MO-12
      MOG=MO-2*(MO/2)
      IF (MOG.GT.0) GO TO 812
      IF (MO.NE.10) GO TO 811
      IYR=YEAR
      IF (MONTH.GT.9) IYR=IYR+1
      IF (IU.GT.0) GO TO 809
      PRINT 900,(FPNAME(IPT,J),J=1,5),IYR
```

```
      GO TO 811
  809 PRINT 904,(FPNAME(IPT,J),J=1,5),IYR
811   PRINT 901,MOCHAR(MONUM),MOCHAR(MONUM+1),(SCALE(ID,I),I=1,5)
812   LDAY=LASTDA(LEAPYR,MO)
      DO 815 IDA=1,LDAY
      AF=WYFW24(IPT,MO,IDA)*QC
      AF=AF/VERT
      IF (AF.LT.0.0) AF=-0.00001
      SF=SFW24(IPT,MO,IDA)*QC
      SF=SF/VERT
      DX=DPX(IPT,MO,IDA)
      IF (IU.EQ.0)DX=DX/25.4
      AL=0.0
      SL=0.0
      IF (AF.GT.0.0) AL=ALOG(AF)+CYL4
      IF (SF.GT.0.0) SL=ALOG(SF)+CYL4
      LA=(AL/PMAX)*100.0+1.5
      LS=(SL/PMAX)*100.0+1.5
      IF (LA.GT.101) LA=101
      IF (LS.GT.101) LS=101
      IF (LA.LT.1) LA=1
      IF (LS.LT.1) LS=1
      AORD=ORD(LA)
      SORD=ORD(LS)
      IF(AF.GE.0.0) ORD(LA)=PLUS
      ORD(LS)=ASTER
      IF (IU.EQ.0) GO TO 818
      PRINT 902,IDA,ORD,SF,AF,DX
      GO TO 819
  818 PRINT 905,IDA,ORD,SF,AF,DX
  819 ORD(LA)=AORD
      ORD(LS)=SORD
815   CONTINUE
      IF (MOG.EQ.0) GO TO 810
      MO6=MONUM/2
      LSKIP=LC(LEAPYR,MO6)
      IF (LSKIP.EQ.0)  GO TO 810
      DO 814 J=1,LSKIP
814   PRINT 903
810   CONTINUE
C FORMAT STATEMENTS
900   FORMAT (1H ,37HSEMI-LOG MEAN DAILY FLOW PLOT(INCHES),5X,5A4,7X,
     113HWATER YEAR 19,I2,5X,25H*=SIMULATED     +=OBSERVED)
  901 FORMAT (1H ,A3,1H-,A3,9X,F10.3,4(10X,F10.3),4X,4HSIM.,3X,4HOBS.,
     11X,9HRAIN+MELT)
  902 FORMAT (1H ,I2,1X,101A1,2X,2F8.3,F6.1)
903   FORMAT (1H )
  904 FORMAT (1H ,33HSEMI-LOG MEAN DAILY FLOW PLOT(MM),5X,5A4,7X,
     113HWATER YEAR 19,I2,5X,24H*=SIMULATED     +=OBSERVED)
  905 FORMAT (1H ,I2,1X,101A1,2X,2F8.4,F6.2)
      RETURN
      END
```

*PRT,S .LPLOT

MORRIS*TPF$(0).LPLOT

```
      SUSROUTINE LPLOT
C MEAN DAILY FLOW FOR PRINTER OUTPUT
      REAL MOCHAR(12)
      DIMENSION LASTDA(2,12),SCALE(10),ORD(101),LC(2,6),UNITS(2)
C GENERAL PROGRAM VARIABLES
      INTEGER ROUTE,TRO,SNOW,SNOWA,YRIN,YR1,SGIN,TPTS,STORE,YEAR,PLT6HR,
     1SAVEFW,TSAVE,COMPAR,PTEST,PLOT,CTEST,       SIXIN,OBSER,STDA,STP6,
     2YR2,USGSID,STAT,PEG
      REAL INFRO
      COMMON/G/MONTH,MOIN,LAST,ROUTE,NGAGES,TRO,SNOW,SNOWA(12),YRIN,
     1NPEGS,YR1,NPTS,SGIN(3),TPTS,STORE,BASIN(20),YEAR,SSF(3,12),
     2SOF(3,12),PLT6HR,SAVEFW,DUMMY(4,31),TSAVE,COMPAR(3),PTEST,PLOT(3),
     3LINEP,INFRO(20),PLOTMX(3),CTEST,FSFLOW(3),USGSID(3),PEG(5),STAT,
     4YR2,AREA(6),SIXIN(3),OBSER(3),STDA(2,10),STP6(2,10),IYEAR1(3),IPT,
     5METRIC(3)
C DAILY PLOT DATA ARRAYS
      COMMON/PD/DPX(3,12,31),SFW24(3,12,31),WYFW24(3,12,31)
C TIME SERIES IDENTIFICATIONS AND DESCRIPTIONS.
      COMMON/TSID/AID(5,3),ANAME(5,5),PEID(3,3),FPNAME(6,5)
      DATA MOCHAR/3HOCT,3HNOV,3HDEC,3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,3HJUN,
     13HJUL,3HAUG,3HSEP/
      DATA LASTDA/31,31,28,29,31,31,30,30,31,31,30,30,31,31,31,31,30,30,
     131,31,30,30,31,31/
      DATA LC/3,3,3,3,6,5,4,4,4,4,0,0/
      DATA UNITS/4HCFSD,4HCMSD/
      DATA DOT,BLANK,ASTER,PLUS/1H.,1H ,1H*,1H+/
      IU=METRIC(IPT)
      ID=IU+1
      QC=1.0
      IF (IU.EQ.0)QC=35.3147
      DO 816 I=1,100
      ORD(I)=BLANK
816   CONTINUE
      DO 817 I=1,101,10
      ORD(I)=DOT
817   CONTINUE
      LEAPYR=1
      IF ((YEAR-4*(YEAR/4)).EQ.0) LEAPYR=2
      PMAX=PLOTMX(IPT)
      DO 810 MONUM=1,12
      MO=MONUM+9
      IF (MO.GT.12) MO=MO-12
      MOG=MO-2*(MO/2)
      IF (MOG.GT.0) GO TO 812
      IF (MO.NE.10) GO TO 811
      IYR=YEAR
      IF (MONTH.GT.9) IYR=IYR+1
      PRINT 900,(FPNAME(IPT,J),J=1,5),IYR,UNITS(ID)
811   DO 813 J=1,10
      DEC=J
813   SCALE(J)=DEC*0.1*PMAX
      PRINT 901,MOCHAR(MONUM),MOCHAR(MONUM+1),SCALE
812   LDAY=LASTDA(LEAPYR,MO)
      DO 815 IDA=1,LDAY
      AF=WYFW24(IPT,MO,IDA)*QC
      IF (AF.LT.0.0)AF=-0.01
```

```
      SF=SFW24(IPT,MO,IDA)*QC
      DX=DPX(IPT,MO,IDA)
      IF (IU.EQ.0)DX=DX/25.4
      LA=(AF/PMAX)*100.0+1.5
      LS=(SF/PMAX)*100.0+1.5
      IF (LA.GT.101) LA=101
      IF (LS.GT.101) LS=101
      AORD=ORD(LA)
      SORD=ORD(LS)
      IF (AF.GE.0.0)ORD(LA)=PLUS
      ORD(LS)=ASTER
      IF (IU.GT.0) GO TO 818
      PRINT 902,IDA,ORD,SF,AF,DX
      GO TO 819
  818 PRINT 904,IDA,ORD,SF,AF,DX
  819 ORD(LA)=AORD
      ORD(LS)=SORD
815   CONTINUE
      IF (MOG.EQ.0) GO TO 810
      MO6=MONUM/2
      LSKIP=LC(LEAPYR     ,MO6)
      IF (LSKIP.EQ.0)  GO TO 810
      DO 814 J=1,LSKIP
814   PRINT 903
810   CONTINUE
C FORMAT STATEMENTS
  900 FORMAT (1H ,20HMEAN DAILY FLOW PLOT,4X,5A4,4X,13HWATER YEAR 19,I2,
     15X,24H*=SIMULATED    +=OBSERVED,4X,6HUNITS-,A4)
  901 FORMAT (1H ,A3,1H-,A3,F9.1,9F10.1,4X,4HSIM.,3X,4HOBS.,1X,
     19HRAIN+MELT)
  902 FORMAT (1H ,I2,1X,101A1,2X,2F8.1,F6.2)
903   FORMAT (1H )
  904 FORMAT (1H ,I2,1X,101A1,2X,2F8.3,F6.1)
      RETURN
      END
```

```
•PRT,S   .SNOW
```

```
MORRIS*TPF$(0).SNOW
      C  ***   DUMMY SNOW SUBROUTINES
      C  ***
            SUBROUTINE SNOW
            ENTRY SNOWPM(A,B)
            RETURN
            ENTRY SNOWIN(A,B,C,D)
            RETURN
            ENTRY PACK(I,J,K,L,M,N)
            RETURN
            ENTRY SNOWOT(I,J,K,L)
            RETURN
            END

@BRKPT  PRINT$
```

APPENDIX B

SAMPLE LISTING FROM WATERSHED BASIC DATA SET

This sample output is from the basic data set used to calibrate the Elk River at Fayetteville watershed. Data type is separated by the term "station." Station 1 lists TA MBP, Station 2 downstream, zone MZP, and Station 3 upstream, MZP. All areal means are for six-hour periods, with days separated by / . Station 4 lists PE, and station 5, mean daily flow.

●BOX .FAYETTFEICHS. RUN AT FAYETTEVILLE,TN. OUTPUT FEICH.

```
MM        MM      NN        NN      WW        WW        SSSSSSSS        FFFFFFFFFFFF      TTTTTTTTTTTT
MMM      MMM      NNN       NN      WW        WW       SSSSSSSSSS       FFFFFFFFFFFF      TTTTTTTTTTTT
MMMM    MMMM      NNNN      NN      WW        WW      SS        SS      FF                     TT
MMMMM  MMMMM      NNNNN     NN      WW        WW      SSS       SS      FF                     TT
MM MMMMMM MM      NN NNN    NN      WW        WW        SSS             FF                     TT
MM  MMMM  MM      NN  NNN   NN      WW   WW   WW          SSS           FFFFFFFF               TT
MM   MM   MM      NN   NNN  NN      WW  WWWW  WW            SSS         FFFFFFFF               TT
MM        MM      NN    NNN NN      WW WWWWWW WW              SSS       FF                     TT
MM        MM      NN     NNNNN      WWWWW  WWWWW      SS        SS      FF                     TT
MM        MM      NN      NNNN      WWWW    WWWW      SS        SS      FF                     TT
MM        MM      NN       NNN      WWW      WWW       SSSSSSSSSS       FF                     TT
MM        MM      NN        NN      WW        WW        SSSSSSSS        FF                     TT

    0000          555555555555      555555555555      555555555555          0000                11
  00000000        555555555555      555555555555      555555555555        00000000             111
 000    000       55                55                55                 000    000           1111
000      000      55                55                55                000      000            11
00        00      55                55                55                00        00            11
00        00      5555555555        5555555555        5555555555        00        00            11
00        00      55555555555       55555555555       55555555555       00        00            11
00        00                55                55                55      00        00            11
000      000                55                55                55      000      000            11
 000    000       55        55      55        55      55        55       000    000             11
  00000000         5555555555        5555555555        5555555555         00000000            111111
    0000             55555555          55555555          55555555           0000              111111

FFFFFFFFFFFF        AAAAAAAA        YY        YY      EEEEEEEEEEEE      TTTTTTTTTTTT      TTTTTTTTTTTT
FFFFFFFFFFFF       AAAAAAAAAA       YYY      YYY      EEEEEEEEEEEE      TTTTTTTTTTTT      TTTTTTTTTTTT
FF                AA        AA       YYY    YYY       EE                     TT                TT
FF                AA        AA        YYY  YYY        EE                     TT                TT
FF                AA        AA         YYYYYY         EE                     TT                TT
FFFFFFFF          AAAAAAAAAAAA          YYYY          EEEEEEEE               TT                TT
FFFFFFFF          AAAAAAAAAAAA           YY           EEEEEEEE               TT                TT
FF                AA        AA           YY           EE                     TT                TT
FF                AA        AA           YY           EE                     TT                TT
FF                AA        AA           YY           EE                     TT                TT
FF                AA        AA           YY           EEEEEEEEEEEE           TT                TT
FF                AA        AA           YY           EEEEEEEEEEEE           TT                TT

FFFFFFFFFFFF      EEEEEEEEEEEE          IIIIII          CCCCCCCC        HH        HH        SSSSSSSS
FFFFFFFFFFFF      EEEEEEEEEEEE          IIIIII         CCCCCCCCCC       HH        HH       SSSSSSSSSS
FF                EE                      II          CC        CC      HH        HH      SS        SS
FF                EE                      II          CC        CC      HH        HH      SSS       SS
FF                EE                      II          CC                HH        HH        SSS
FFFFFFFF          EEEEEEEE                II          CC                HHHHHHHHHHHH          SSS
FFFFFFFF          EEEEEEEE                II          CC                HHHHHHHHHHHH            SSS
FF                EE                      II          CC                HH        HH              SSS
FF                EE                      II          CC        CC      HH        HH      SS        SS
FF                EE                      II          CC        CC      HH        HH      SS        SS
FF                EEEEEEEEEEEE          IIIIII         CCCCCCCCCC       HH        HH       SSSSSSSSSS
FF                EEEEEEEEEEEE          IIIIII          CCCCCCCC        HH        HH        SSSSSSSS
```

ELK ABV FAYETTEVILLE, TENN. RB155

DAY STATION 1 MONTH 1 YEAR 1964

1	.75	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
5	.00	.00	.00	.00/	.00	.46	.33	.20/	.00	.00	.00	.00/	.00	.00	.00	.70/
9	.22	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.09	.14	.00	.13/
13	.00	.00	.01	.00/	.00	.00	.03	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.36/	.03	.00	.00	.00/
21	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.26	.87	.43	.17/
25	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.12	.03	.09/				

DAY STATION 2 MONTH 1 YEAR 1964

1	.62	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
5	.00	.00	.00	.00/	.00	.47	.33	.24/	.00	.00	.00	.00/	.00	.00	.00	.62/
9	.18	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.10	.12	.00	.10/
13	.00	.00	.01	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.34/	.02	.00	.00	.00/
21	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.23	.81	.41	.02/
25	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.07	.02	.05/				

DAY STATION 3 MONTH 1 YEAR 1964

1	.87	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
5	.00	.00	.00	.00/	.00	.45	.32	.15/	.00	.00	.00	.00/	.00	.00	.00	.77/
9	.25	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.08	.17	.00	.15/
13	.00	.00	.02	.00/	.00	.00	.05	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.38/	.03	.00	.00	.00/
21	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.29	.91	.44	.30/
25	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.15	.04	.12/				

DAY STATION 4 MONTH 1 YEAR 1964

1	.035	.062	.057	.046	.023	.009	.025	.012	.025	.041	
11	.034	.005	.031	.020	.025	.022	.028	.041	.063	.075	
21	.091	.054	.050	.015	.073	.074	.043	.036	.040	.049	.027

DAY STATION 5 MONTH 1 YEAR 1964

1	380.000	444.000	352.000	864.000	1030.000	1580.000	3320.000	2760.000	4650.000	4190.000	
11	2790.000	2000.000	1870.000	1510.000	1190.000	1190.000	1100.000	958.000	904.000	662.000	
21	1100.000	1000.000	963.000	2040.000	5340.000	4660.000	3480.000	2700.000	1700.000	1410.000	1330.000

DAY STATION 1 MONTH 2 YEAR 1964

1	.04	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
5	.00	.00	.19	.18/	.11	.00	.00	.00/	.00	.00	.02	.00/	.00	.00	.00	.00/
9	.00	.00	.00	.00/	.00	.00	.05	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
13	.25	.63	.10	.00/	.00	.00	.01	.00/	.43	.83	.18	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.11/	.36	.09	.00	.02/	.15	.00	.04	.00/	.00	.08	.00	.00/
21	.00	.00	.03	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
25	.00	.15	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.25	.31	.00	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/				

DAY STATION 2 MONTH 2 YEAR 1964

1	.02	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
5	.00	.00	.19	.17/	.11	.00	.00	.00/	.00	.00	.01	.00/	.00	.00	.00	.00/
9	.00	.00	.00	.00/	.00	.00	.04	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
13	.25	.57	.09	.00/	.00	.00	.00	.00/	.40	.83	.18	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.10/	.35	.08	.00	.02/	.11	.00	.03	.00/	.00	.02	.00	.00/
21	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
25	.00	.09	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.27	.33	.00	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/				

DAY STATION 3 MONTH 2 YEAR 1964

1	.06	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/

5	.00	.00	.20	.19/	.12	.00	.00	.00/	.00	.00	.04	.00/	.00	.00	.00	.00/
9	.00	.00	.00	.00/	.00	.00	.05	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
13	.26	.69	.12	.00/	.00	.00	.02	.00/	.44	.82	.18	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.11/	.37	.10	.00	.03/	.18	.00	.05	.00/	.00	.13	.00	.00/
21	.00	.00	.06	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
25	.00	.20	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.23	.30	.00	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/				
DAY	STATION 4	MONTH 2	YEAR 1964													
1	.052	.054	.071	.060	.032	.053	.062	.057	.058	.049						
11	.049	.073	.017	.033	.043	.042	.039	.019	.030	.034						
21	.031	.033	.048	.052	.057	.024	.045	.059	.063	.999	.999					
DAY	STATION 5	MONTH 2	YEAR 1964													
1	1320.000	1260.000	1200.000	1120.000	932.000	1250.000	1260.000	1150.000	1040.000	990.000						
11	950.000	900.000	1240.000	1830.000	4630.000	7950.000	6430.000	5650.000	4660.000	3720.000						
21	2960.000	2370.000	2070.000	1800.000	1580.000	1310.000	1300.000	1420.000	1720.000	.000	.000					
DAY	STATION 1	MONTH 3	YEAR 1964													
1	.00	.02	.00	.00/	.00	.97	.04	.12/	.00	.00	.00	.00/	.04	.00	.57	.00/
5	.00	.00	.44	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.02	.00/
9	.00	.00	.08	.65/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
13	.00	.00	.00	.02/	.12	.43	1.03	.99/	.48	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.24	.09/	.00	.00	.03	.62/
21	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
25	.90	.25	.09	.71/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.03	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/				
DAY	STATION 2	MONTH 3	YEAR 1964													
1	.00	.01	.00	.00/	.00	1.03	.04	.03/	.00	.00	.00	.00/	.08	.01	.81	.00/
5	.00	.00	.12	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.01	.00/
9	.00	.00	.13	.52/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
13	.00	.00	.00	.03/	.18	.59	1.37	.85/	.39	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.22	.04/	.00	.00	.06	.53/
21	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.01/
25	.89	.24	.09	.59/	.00	.00	.00	.00/	00	.00	.00	.00/	.00	.00	.03	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/				
DAY	STATION 3	MONTH 3	YEAR 1964													
1	.00	.03	.00	.00/	.00	.90	.04	.20/	.00	.00	.00	.00/	.01	.00	.37	.00/
5	.00	.00	.72	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.04	.00/
9	.00	.00	.04	.75/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
13	.00	.00	.00	.01/	.07	.29	.73	1.11/	.55	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.25	.13/	.00	.00	.02	.68/
21	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
25	.90	.26	.09	.82/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.02	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/				
DAY	STATION 4	MONTH 3	YEAR 1964													
1	.093	.060	.073	.052	.109	.124	.083	.081	.049	.069						
11	.097	.087	.132	.098	.111	.099	.101	.106	.098	.108						
21	.075	.062	.090	.120	.048	.073	.097	.091	.099	.081	.116					
DAY	STATION 5	MONTH 3	YEAR 1964													
1	1800.000	2920.000	5290.000	4800.000	7630.000	7760.000	4960.000	3760.000	2740.000	3220.000						
11	3040.000	2410.000	2380.000	4820.000	17500.000	19800.000	15400.000	8550.000	3730.000	3230.000						
21	3480.000	3560.000	3190.000	2400.000	3990.000	7870.000	7980.000	5500.000	3550.000	2520.000	2290.000					
DAY	STATION 1	MONTH 4	YEAR 1964													
1	.00	.02	.02	.00/	.00	.00	.00	.00/	.00	.00	.00	.48/	1.11	.14	.00	.00/
5	.00	.00	.00	.86/	.00	.00	.00	.14/	.58	.50	.00	.00/	.00	.00	.01	.00/
9	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.01	.00	.05	.04/
13	.32	1.09	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
21	.00	.00	.00	.00/	.02	.07	.00	.00/	.00	.12	1.04	.00/	.00	.00	.61	.18/

25	.01	.00	.00	.00/	.47	.04	.00	.40/	1.24	.00	.00	.00/	.00	.00	.04	.00/
29	.00	.00	.02	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/				
DAY				STATION 2		MONTH 4		YEAR 1964								
1	.00	.04	.03	.00/	.00	.00	.00	.00/	.00	.00	.00	.56/	1.24	.15	.00	.00/
5	.00	.00	.00	.88/	.00	.00	.00	.13/	.50	.42	.00	.00/	.00	.00	.00	.00/
9	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.02	.00	.08	.04/
13	.32	1.02	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
21	.00	.00	.00	.00/	.03	.10	.00	.00/	.00	.15	1.15	.00/	.00	.00	.33	.27/
25	.02	.00	.00	.00/	.36	.06	.00	.39/	1.11	.00	.00	.00/	.00	.00	.01	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/				
DAY				STATION 3		MONTH 4		YEAR 1964								
1	.00	.00	.01	.00/	.00	.00	.00	.00/	.00	.00	.01	.42/	1.00	.13	.00	.00/
5	.00	.00	.00	.85/	.00	.00	.00	.16/	.65	.56	.00	.00/	.00	.00	.01	.00/
9	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.03	.04/
13	.32	1.14	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
21	.00	.00	.00	.00/	.01	.06	.00	.00/	.00	.10	.96	.00/	.00	.00	.85	.10/
25	.01	.00	.00	.00/	.56	.04	.00	.41/	1.33	.00	.00	.00/	.00	.00	.07	.00/
29	.00	.00	.03	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/				
DAY				STATION 4		MONTH 4		YEAR 1964								
1	.134	.175	.150	.091	.111	.140	.116	.122	.099	.115						
11	.145	.118	.114	.114	.127	.173	.169	.147	.138	.162						
21	.147	.121	.100	.093	.102	.118	.171	.167	.147	.118					.999	
DAY				STATION 5		MONTH 4		YEAR 1964								
1	1800.000	1820.000	1840.000	9000.000	8350.000	7760.000	7930.000	9440.000	8400.000	4430.000						
11	2770.000	2640.000	4700.000	6750.000	6090.000	3420.000	2670.000	2090.000	1910.000	1830.000						
21	1780.000	1550.000	1640.000	3510.000	5640.000	4630.000	8890.000	11400.000	9900.000	4780.000					.000	
DAY				STATION 1		MONTH 5		YEAR 1964								
1	.00	.00	.00	.00/	.00	.64	1.23	.33/	.00	.00	.00	.00/	.00	.00	.00	.00/
5	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
9	.00	.00	.00	.00/	.00	.06	.00	.00/	.00	.11	.00	.00/	.17	.04	.00	.04/
13	.11	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.04	.00/
21	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.02	.00/	.00	.00	.00	.00/
25	.00	.00	.00	.00/	.00	.00	.00	.05/	.21	.00	.29	.00/	.03	.00	.57	.00/
29	.00	.00	.09	.00/	.00	.00	.00	.00/	.00	.00	.14	.09/				
DAY				STATION 2		MONTH 5		YEAR 1964								
1	.00	.00	.00	.00/	.00	.75	1.26	.17/	.00	.00	.00	.00/	.00	.00	.00	.00/
5	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
9	.00	.00	.00	.00/	.00	.11	.01	.00/	.00	.04	.00	.00/	.18	.05	.00	.05/
13	.13	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.02	.00/
21	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.01	.00/	.00	.00	.00	.00/
25	.00	.00	.00	.00/	.00	.00	.00	.04/	.17	.00	.23	.00/	.03	.00	.61	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.18	.09/				
DAY				STATION 3		MONTH 5		YEAR 1964								
1	.00	.00	.00	.00/	.00	.57	1.20	.45/	.00	.00	.00	.00/	.00	.00	.00	.00/
5	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
9	.00	.00	.00	.00/	.00	.01	.00	.00/	.00	.17	.00	.00/	.16	.04	.00	.02/
13	.10	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.07	.00/
21	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.02	.00/	.00	.00	.00	.00/
25	.00	.00	.00	.00/	.00	.00	.00	.06/	.25	.00	.33	.00/	.04	.00	.54	.00/
29	.00	.00	.16	.00/	.00	.00	.00	.00/	.00	.00	.12	.09/				
DAY				STATION 4		MONTH 5		YEAR 1964								
1	.173	.134	.152	.172	.196	.204	.201	.203	.153	.144						

11	.163	.162	.168	.155	.143	.163	.168	.162	.169	.181	
21	.171	.187	.195	.175	.163	.183	.207	.159	.155	.146	.120

DAY STATION 5 MONTH 5 YEAR 1964

1	2780.000	3820.000	8010.000	8600.000	4960.000	3060.000	2280.000	1950.000	1760.000	1560.000	
11	1500.000	1600.000	1520.000	1550.000	1320.000	1250.000	1250.000	1160.000	1010.000	886.000	
21	842.000	796.000	693.000	662.000	634.000	598.000	603.000	688.000	1220.000	1020.000	896.000

DAY STATION 1 MONTH 6 YEAR 1964

1	.31	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
5	.00	.00	.00	.16/	.47	.01	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
9	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.08	.76	.45/
13	.00	.00	.02	.03/	.00	.00	.00	.04/	.00	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.03	.06/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
21	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.04	.02/	.00	.00	.00	.00/
25	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.05/	.00	.00	.00	.00/				

DAY STATION 2 MONTH 6 YEAR 1964

1	.28	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
5	.00	.00	.00	.09/	.28	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
9	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.16	1.08	.51/
13	.00	.00	.03	.03/	.00	.00	.00	.03/	.00	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.06	.09/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
21	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.06	.03/	.00	.00	.00	.00/
25	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.03/	.00	.00	.00	.00/				

DAY STATION 3 MONTH 6 YEAR 1964

1	.34	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
5	.00	.00	.00	.21/	.62	.01	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
9	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.46	.39/
13	.00	.00	.02	.03/	.00	.00	.00	.05/	.00	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.01	.03/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	00	.00	.00/
21	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.01	.01/	.00	.00	.00	.00/
25	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.06/	.00	.00	.00	.00/				

DAY STATION 4 MONTH 6 YEAR 1964

1	.158	.160	.166	.167	.190	.180	.190	.230	.220	.224	
11	.212	.214	.215	.230	.218	.169	.172	.229	.238	.244	
21	.208	.207	.220	.223	.221	.204	.212	.222	.156	.173	.999

DAY STATION 5 MONTH 6 YEAR 1964

1	738.000	616.000	567.000	540.000	524.000	536.000	608.000	634.000	594.000	468.000	
11	412.000	372.000	1120.000	954.000	994.000	954.000	752.000	488.000	432.000	404.000	
21	388.000	376.000	380.000	388.000	348.000	336.000	328.000	300.000	276.000	268.000	.000

DAY STATION 1 MONTH 7 YEAR 1964

1	.02	.20	.05	.00/	.00	.00	.00	.21/	.00	.00	.00	.00/	.10	.08	.00	.00/
5	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.02	.00/	.64	.00	.00	.00/
9	.00	.00	.00	.00/	.00	.00	.34	.00/	.00	.00	.01	.33/	1.59	.18	.16	.00/
13	.00	.00	.01	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.00/	.00	.00	.02	.00/	.00	.01	.01	.11/	.32	.00	.00	.00/
21	.00	.01	.01	.02/	.00	.00	.00	.00/	.00	.00	.19	.00/	.00	.04	.93	.00/
25	.00	.00	1.05	.00/	.00	.00	.22	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
29	.00	.00	.03	.00/	.00	.00	.16	.11/	.00	.00	.01	.00/				

DAY STATION 2 MONTH 7 YEAR 1964

1	.02	.13	.06	.00/	.00	.00	.00	.34/	.00	.00	.00	.00/	.19	.13	.00	.00/
5	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.03	.00	.00	.00/
9	.00	.00	.00	.00/	.00	.00	.44	.00/	.00	.00	.01	.33/	1.65	.17	.15	.00/
13	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.00/	.00	.00	.03	.00/	.00	.02	.01	.03/	.10	.00	.00	.00/
21	.00	.02	.02	.04/	.00	.00	.00	.00/	.00	.00	.01	.00/	.00	.10	1.25	.00/

25	.00	.00	1.21	.00/	.00	.00	.33	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
29	.00	.00	.05	.00/	.00	.00	.03	.10/	.00	.00	.01	.00/				
DAY			STATION 3		MONTH 7		YEAR 1964									
1	.02	.26	.05	.00/	.00	.00	.00	.10/	.00	.00	.00	.00/	.03	.03	.00	.00/
5	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	1.17	.00	.00	.00/
9	.00	.00	.00	.00/	.00	.00	.24	.00/	.00	.00	.01	.33/	1.55	.18	.17	.00/
13	.00	.00	.01	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
17	.00	.00	.00	.00/	.00	.00	.01	.00/	.00	.00	.00	.17/	.50	.00	.00	.00/
21	.00	.00	.01	.01/	.00	.00	.00	.00/	.00	.00	.34	.00/	.00	.00	.62	.00/
25	.00	.00	.89	.00/	.00	.00	.12	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
29	.00	.00	.02	.00/	.00	.00	.26	.12/	.00	.00	.00	.00/				
DAY			STATION 4		MONTH 7		YEAR 1964									
1	.178	.182	.175	.191	.195	.208	.221	.199	.184	.191						
11	.149	.175	.176	.174	.176	.184	.182	.188	.206	.191						
21	.190	.186	.183	.193	.189	.198	.193	.201	.184	.176	.195					
DAY			STATION 5		MONTH 7		YEAR 1964									
1	288.000	312.000	756.000	376.000	372.000	348.000	352.000	376.000	320.000	320.000						
11	356.000	1470.000	2000.000	1160.000	882.000	652.000	500.000	420.000	388.000	380.000						
21	597.000	652.000	585.000	532.000	516.000	652.000	576.000	576.000	536.000	524.000	711.000					
DAY			STATION 1		MONTH 8		YEAR 1964									
1	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.13	.00	.12	.00/
5	.00	.00	.26	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.34	.00/
9	.00	.00	.09	.00/	.00	.00	.01	.01/	.00	.00	.00	.00/	.00	.00	.04	.00/
13	.00	.00	.00	.00/	.00	.00	.00	.00/	.20	.95	.33	.24/	.52	.61	.01	.00/
17	.00	.00	.01	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
21	.00	.00	.04	.00/	.00	.00	.17	.09/	.01	.00	.00	.00/	.00	.00	.00	.00/
25	.00	.00	.25	.11/	.05	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/				
DAY			STATION 2		MONTH 8		YEAR 1964									
1	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.06	.00	.24	.00/
5	.00	.00	.37	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.21	.00/
9	.00	.00	.00	.00/	.00	.00	.00	.01/	.00	.00	.00	.00/	.00	.00	.00	.00/
13	.00	.00	.00	.00/	.00	.00	.00	.00/	.19	.87	.33	.23/	.50	.53	.01	.00/
17	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
21	.00	.00	.04	.00/	.00	.00	.23	.12/	.01	.00	.00	.00/	.00	.00	.00	.00/
25	.00	.00	.31	.11/	.04	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/				
DAY			STATION 3		MONTH 8		YEAR 1964									
1	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.18	.00	.02	.00/
5	.00	.00	.17	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.45	.00/
9	.00	.00	.17	.00/	.00	.00	.01	.01/	.00	.00	.00	.00/	.00	.00	.07	.00/
13	.00	.00	.00	.00/	.00	.00	.00	.00/	.22	1.01	.34	.25/	.53	.67	.01	.00/
17	.00	.00	.02	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
21	.00	.00	.05	.00/	.00	.00	.12	.06/	.00	.00	.00	.00/	.00	.00	.00	.00/
25	.00	.00	.21	.11/	.05	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
29	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/				
DAY			STATION 4		MONTH 8		YEAR 1964									
1	.185	.186	.201	.211	.200	.177	.175	.180	.181	.182						
11	.183	.164	.150	.160	.143	.125	.140	.148	.152	.170						
21	.191	.158	.160	.167	.172	.152	.168	.186	.172	.173	.160					
DAY			STATION 5		MONTH 8		YEAR 1964									
1	448.000	400.000	392.000	400.000	400.000	400.000	388.000	380.000	492.000	476.000						
11	448.000	460.000	448.000	428.000	558.000	1490.000	1650.000	1220.000	1660.000	981.000						
21	702.000	594.000	567.000	562.000	540.000	540.000	440.000	396.000	376.000	360.000	348.000					
DAY			STATION 1		MONTH 9		YEAR 1964									
1	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/
5	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/	.00	.00	.00	.00/

VITA 2

David Gordon Morris

Candidate for the Degree of

Doctor of Philosophy

Thesis: STREAMFLOW SYNTHESIS EMPLOYING A MULTI-ZONE HYDROLOGIC MODEL WITH DISTRIBUTED RAINFALL AND DISTRIBUTED PARAMETERS

Major Field: Civil Engineering

Biographical:

Personal Data: Born in Rochester, New York, on August 28, 1938, the son of Albert Douglas and Eleanor Marie MacPherson.

Education: Graduated from Hillcrest High School, Dallas, Texas, in May, 1957; received the Bachelor of Arts in Mathematics from Texas A & M University in 1961, and the Master of Science in Meteorology from Texas A & M University in 1966; received the Master of Science in Bioenvironmental Engineering from Oklahoma State University in 1972. Completed the requirements for the degree of Doctor of Philosophy at Oklahoma State University in July, 1977.

Professional Experience: Aviation Meteorologist, U.S.A.F., 1952-1964; Meteorologist, National Weather Service, 1966-1969; Hydrologist, National Weather Service, 1970-1977.

Honor Societies: Member of Chi Epsilon, The Society of the Sigma Xi, and Phi Kappa Phi.